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Investigation of the Boiled Potato Flavor by Human Sensory and Instrumental Methods

D. Ulrich[1]*, E. Hoberg[1], W. Neugebauer[3], H. Tiemann[2], and U. Darsow[2]

[1]Federal Centre for Breeding Research on Cultivated Plants, Institute for Quality Analysis, Neuer Weg 22/23, D-06484 Quedlinburg, Germany.
Phone: +49-3946-47 232; Fax: +49-3946-47 255; E-Mail: d.ulrich@bafz.de.
[2]Federal Centre for Breeding Research on Cultivated Plants, Institute Agricultural Crops, Groß-Lüsewitz, Germany.
[3]Dragoco, Gerberding & Co. AG, Holzminden, Germany.
*Corresponding author

ABSTRACT

The flavor of boiled potatoes was investigated using sensory and instrumental methods to get basic information concerning sensory features and aroma compounds for use in breeding research and quality control. The sensory odor profiles of three genotypes were found to differ especially in negative sensations like "burnt", "fodder" and "musty". The aroma volatiles were isolated by a modified simultaneous steam distillation and extraction method. Nineteen character impact compounds of boiled potato aroma were pointed out by gas chromatography with nitrogen specific detection, gas chromatography - mass spectrometry and gas chromatography - olfactometry. The comparison of the quantified odor impressions in three genotypes by chromatography - olfactometry revealed the substances responsible for the typical boiled potato odorants and off-flavor notes.

INTRODUCTION

In many areas of the world, potatoes and potato products contribute to healthy nutrition. Potato flavor is an essential quality criterion, which is, in the case of a saturated market, one aspect that the consumer considers when buying the food product. Both potato breeders and quality inspectors demand objective evaluation parameters for sensory quality of plant products. Although consumers often find fault with potato flavor, up to now no generally accepted sensory criteria (sensory profiles) existed. In the past, instrumental analysis was intensively concerned with the flavor of baked and fried potatoes as well as with potato products like chips. In contrast, the flavor of boiled potatoes found only little interest though it plays an important role in some regions (Whitfield and Last, 1991).

The aroma of fresh fruits, such as strawberries or melons, is characterized by a high number of volatile compounds. In comparison with fresh fruits, the aroma of boiled potato stands out by its relatively "weak" but very typical aroma, which is produced from precursors during the cooking process (reaction aroma). The most important aroma contribution (character impact compounds) is made by a comparably small number of volatiles. For a long time methional and different kinds of pyrazines have been known as key compounds (Buttery *et al.*, 1973; Whitfield and Last, 1991; Salinas *et al.*, 1994). Methional is a product of thermal degradation of the amino acid methionine. Pyrazines arise from amino acids and sugars in Maillard and Strecker reactions. Additionally, more than 140 other volatiles have been identified to contribute, more or less, to the aroma impression. Obviously the total number of constituents increases with increasing thermal processing: up to now more than 250 volatiles have been identified in baked potatoes (Whitfield and Last, 1991).

Off-flavor notes are a problem in processed potatoes and potato products. They are caused by dienals (Josephson and Lindsay, 1987; Petersen *et al.*, 1998), (Z)-4-heptenal (Joseph-

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ADDITIONAL KEY WORDS: Cooked potato, potato flavor, potato aroma, human sensory, quantitative descriptive analysis, gas chromatography, gas chromatography olfactometry, character impact compounds.

GC-O	gas chromatography - olfactometry
IST	internal standard
MS	mass spectrometry
TIC	total ion chromatogram
PND	phosphorous nitrogen specific detector
QDA	quantitative descriptive analysis
RI	retention index
SDE	simultaneous steam distillation - solvent extraction

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son and Lindsay, 1987) or increased concentration of pyrazines (Sapers *et al.*, 1971). The weighing of the quantitative contributions of the positive as well as the negative substances established for instance by the gas chromatography - olfactometry (GC-O) has not been published until now. This lack of information means that there is no base for an application of instrumental analysis in quality control which is desirable for the breeding process.

Therefore we conducted this research to investigate the chemical basis for the flavor of boiled potatoes from different genetic backgrounds. The results from a method for the evaluation of the sensory profile, on the one hand, and the data of instrumental aroma analysis, on the other hand, are shown. The findings of both methods are compared.

MATERIAL AND METHODS

Potatoes—The potato genotypes "A" (German variety "Adretta"), "L" (German variety "Likaria") and "S" (breeding clone "St 1,365") were harvested in the experimental garden of the Institute for Quality Analysis in Quedlinburg. The potatoes were stored for one month in a cooling cell between 2 and 4 C from harvest to analysis.

Sensory Evaluation—The boiled potatoes were prepared with a standardized method. A sample of 1 kg was washed and boiled only with water (400 ml) in a household pressure cooker for 15 minutes. The tubers were peeled immediately after cooking, and then mashed to get a randomized sample. The mashed samples were served in warm glasses on a warm plate. The glasses were closed until the odor evaluation by the tester. The sensory evaluation was carried out by a trained panel of 15 members. The typical potato features corresponding to the demands of the instrumental analysis for flavor characterization were developed by the panel and trained in special exercises. Odor and retronasal odor were the main focus before taste and mouth sensation. A maximum of five samples was tested per session, each with two replications. The evaluated parameters were listed on a special form for potato. A non-graded linear scale (10 cm) was used for the quantification of the features (Hoberg *et al.*, 1998). The panelists marks on this scale were measured and normalized to make out the sensory profiles.

Simultaneous Steam Distillation - Solvent Extraction (SDE)—The SDE apparatus originally described by Likens and Nickerson (1964) was modified for applications with solvents of a specific weight higher than water (Ulrich *et al.*, 1997; Ulrich *et al.*, 1998a). The following procedure was used. The raw potatoes were peeled, cut into 1 cm long pieces to prevent input of impurities and to support the release of volatiles, and than boiled in the SDE-apparatus. A four liter round bottom flask fitted with stirrer, foam breaker and electric heater was filled with 1330 ml distilled water, 1000 g potato cuts, 2.2 g sodium chloride. 24 ml of 1,1,2-trichlorotrifluoroethane ("Kaltron"; FLUKA, art. no. 91440, puriss. p.a. >99.5 %; distilled) and 6 ml of dichloromethane (ALDRICH, art. no. D 6,510-0, 99.6 %; distilled) were added to the extraction device of the Likens-Nickerson-apparatus and heated in a water bath at 50 C. The samples were distilled at 100 C and extracted for 2 hours.

The extracts were concentrated from 30 ml to 100 µl in a modified Kuderna-Danish-concentrator fitted with a three-ball Snyder column.

Gas Chromatography with Nitrogen Specific Detection (GC-PND)—Chromatographic analysis was conducted using a Hewlett-Packard system HP 6890 equipped with a ceramic phosphorous-nitrogen-detector (PND) and a polar column (INNO-wax 30 m x 0.32 mm ID / 0.5 µm; 2 ml hydrogen / min; temperature programme: 45 C - 1.5 C/min - 180 C).

Gas Chromatography - Mass Spectrometry (GC-MS)—Identification of volatiles in the extracts was carried out on a Hewlett-Packard MSD system model 5972 coupled with a HP 5890 Series 2 plus gas chromatograph. Data were processed using data base NBS75K as well as Wiley138. The instrument was equipped with a polar column (INNO-wax 60 m x 0.25 mm ID / 0.25 µm; 1 ml helium / min; temperature programme: 45 C - 1.5 C/min - 180 C).

Gas Chromatography - Olfactometry (GC-O)—For GC-O analysis a specially designed Hewlett-Packard gas chromatograph model 5890 A was used, equipped with FID and sniffing port. The following separation parameters were used: injector 250 C; split 10 ml, polar column HP-INNO wax 30 m x 0.32 mm ID / 0.5 µm; 2 ml hydrogen / min; temperature programme: 50 C - 3 C/min - 180 C, FID 250 C. At the end of the capillary the carrier gas was split 50 % to FID and 50 % to sniffing port. For the aroma extract dilution analysis (AEDA) the extracts were diluted in ascending order with solvent in a geometrical line (Ullrich and Grosch, 1987; Acree and Teranishi, 1993).

RESULTS AND DISCUSSION

In the present paper the parameters "flavor" and "aroma" are used in correspondence with their scientific definition. Therefore, "flavor" comprises the totality of the

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human sense impressions taste, aroma and texture whereas "aroma" includes the nasal and retronasal smell caused by volatile compounds.

Sensory Evaluation

The three largely differing sensory profiles of the potato genotypes "A", "L"and "S" are shown in figure 1. The beams of the profiles present the normalized odor features "sweet-like", "earthy", "burnt", "fodder", "untypical", "musty", "fruity", and "typical". "A" is the most preferred genotype of the three compared types. It is mainly characterized by "sweet-like", "earthy", "fruity", and "typical". The other characters "burnt", "fodder", "musty" are often found in potatoes, but they are more negatively estimated. "Untypical" smell is not accepted by consumers. The tested batch of "L" is found to smell much more like "fodder", "musty" and "untypical". "S" has the highest intensity of "burnt", "untypical" and also strong "musty". The positive feature "earthy" is minimized against "L" and "A", but also unpleasant "fodder". That is the genotypes "L" and "S" are characterized by more intensive negative smell sensations. The results pointed out represent parameters of a quantitative descriptive analysis (QDA) which can support the interpretation of instrumental analysis data. QDA-parameters are not comparable with results of assessment of culinary quality which is commonly used in selection process of variety breeding.

Aroma Analysis

With the aid of aroma analysis, those highly volatile compounds were measured which could be nasally and retronasally detected by the human sense. These substances characterize the smell (aroma) of the potatoes. The important tasks were first the differentiation between smelling and non-smelling compounds and second the quantification of the contribution of a distinct substance to the total aroma perception. That means to find out the character impact compounds.

Sample preparation—The decision for an equivalent sample preparation method is a prerequisite for good results in aroma analysis. The isolation of aroma compounds from the matrix of boiled potatoes is very difficult because of the high starch content. Common and simple methods like liquid-liquid-extraction are not applicable (Petersen *et al.*, 1998). The combination of the cooking process with the

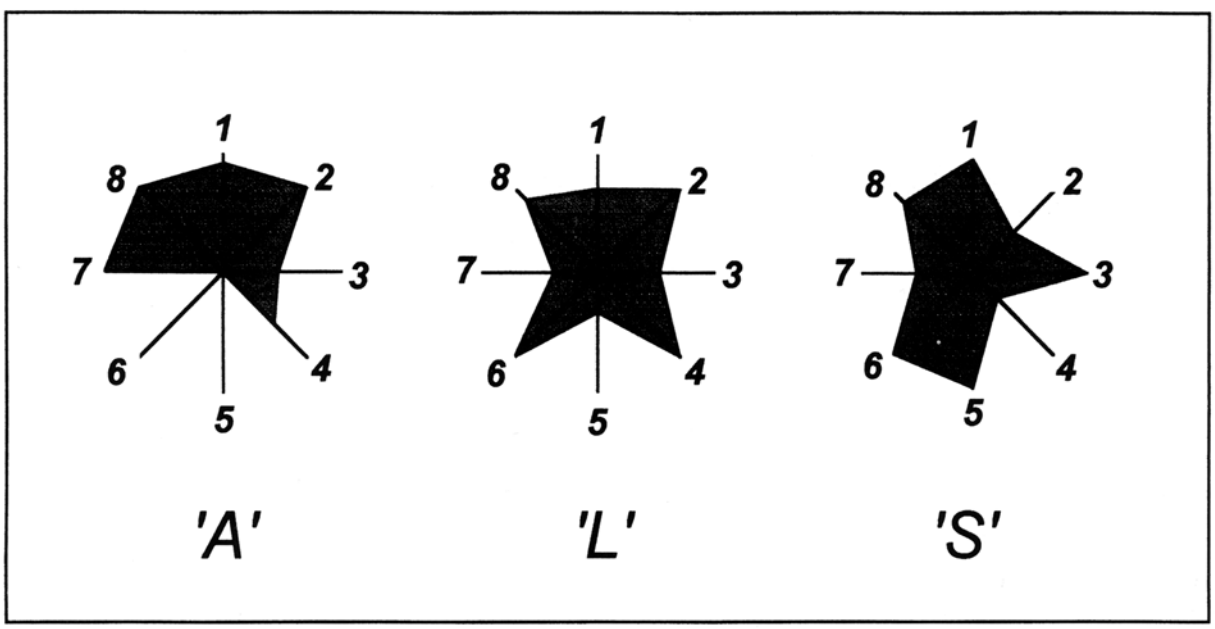

FIGURE 1
Sensory profiles (quantitative descriptive analysis) of the three potato genotypes "Adretta" (A), "Likaria" (L) and "St 1,365" (S). Sensory characters for odor profile: (1) sweet-like, (2) earthy, (3) burnt, (4) fodder, (5) untypical, (6) musty, (7) fruity and (8) typical. The length of each line from the origin represents the normalized intensity of odor perceptions. The normalization was carried out by setting the highest value of the three genotypes to 100% for each character.

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simultaneous aroma extraction was pointed out as a suitable method (Salinas *et al.*, 1994; Ulrich *et al.*, 1997; Ulrich *et al.*, 1998b). The thermal formation of the aroma compounds from the raw potato slices during the cooking process and the transfer of the aroma into organic solvents took place in a totally closed apparatus without losses. In opposition to Salinas *et al.* (1994) a mixture of solvents was used to improve the extraction of polar substances like pyrazines.

From 1,000 g raw potatoes, 100 µl (approx. 100 mg) of highly concentrated extract were obtained by solvent evaporation from the original extract; that is the concentration factor yields about 10,000. An important fact is, that in spite of the high concentration factor, the sensory character is the typical one of boiled potatoes. The sample preparation method employed here is suited for basic investigations of the potato aroma, but it is under no circumstances a rapid method for routine quality evaluation.

Chromatographic Separation and Substance Identification—Figure 2a shows the chromatografic separation of volatiles from a potato extract with a wax column. The chromatogram comprises a high number of gas chromatographic peaks because of the high concentration of the extract. More than 100 substances were identifiable in a single run with the mass spectrometric detector. Using the nitrogen specific

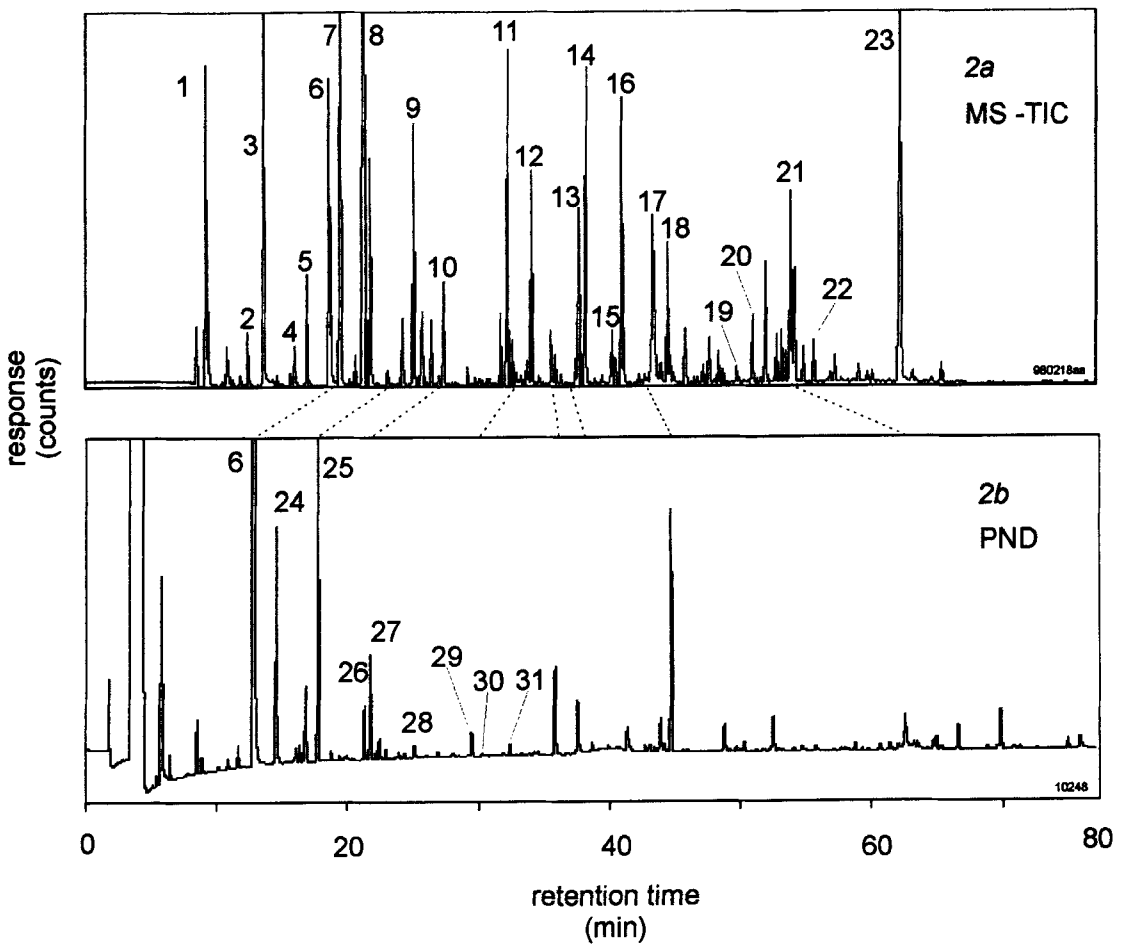

FIGURE 2
Chromatographic separation of a potato extract from genotype "St 1,365" detected by MS. Total Ion Chromatogram (2a) and PND (2b). Some important volatiles are marked: (1) 2,3-butanedione; (2) 2,3-pentanedione; (3) hexanal; (4) 1-penten-3-ol; (5) pyridine; (6) 2-methyl-1-butanol; (7) 2-pentylfuran; (8) (E)-2-(1-pentenyl)furan; (9) 1-hexanol; (10) (E)-2-octenal; (11) 2-furancarboxaldehyde; (12) (E)-2-nonenal; (13) internal standard (1-octanol); (14) (E,Z)-2,6-nonadienal; (15) unknown; (16) phenylacetaldehyde; (17) (Z)-3-nonen-1-ol; (18) β-damascenone; (19) 2,4-decadienal; (20) benzyl alcohol; (21) phenylethyl alcohol; (22) unknown; (24) pyrazine; (25) methylpyrazine; (26) 2,5-dimethylpyrazine; (27) 2,6 dimethylpyrazine; (28) 2-ethyl-6-methylpyrazine; (29) 2,6-diethylpyrazine; (30) 3-ethyl-2,5-dimethylpyrazine; (31) 2-ethyl-3,5-dimethylpyrazine. Identical compounds in chromatograms 2a and 2b are connected by dotted lines.

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detector (PND), the separation presented in figure 2b shows about 25 high peaks. But the results obtained with both the mass spectrometric and the nitrogen specific detectors are not sufficient for direct conclusions to the potato aroma. The contribution of a distinct compound to aroma does not depend on its concentration level but on the aroma value, that is the concentration divided by its smell threshold value. Essential aroma compounds, like alkyl pyrazines, are characterized by extremely low odor thresholds (Grosch *et al.*, 1996); therefore they give significant aroma impressions at sub-ppb-levels. Figure 2b makes it clear that the quantification of some of these substances is difficult even with the nitrogen specific detector.

Gaschromatography - Olfactometry—Character impact compounds were determined by GC-O; it uses the connection of a gas chromatograph with an FID-detector and the human nose (Ullrich and Grosch, 1987; Acree and Teranishi, 1993). With the aid of this method it is possible, on the one hand, to assign the sensory quality to the gas chromatographic peak (also to peaks caused by non-identified substances), on the other hand, to establish the quantitative contribution of a distinct substance to the aroma using a suitable methodology (AEDA).

The olfactograms in figure 3 present the results of an AEDA from three potato genotypes. Each bar in the olfactograms corresponds to a substance with a plainly recognizable odor. Weak sense impressions with flavor dilution factors (FD-factors) smaller than two were neglected to reach a good survey. The three genotypes are characterized by similar basic patterns, especially for the intensive and very intensive odor notes. The substances assigned to the bars b, c, h, i, j, k, l, m and r in table 1 obviously form the "basic aroma" of the boiled potatoes. Qualitative differences between the genotypes are clearly manifested in substances which belong to the off-flavors (peaks a, e, n, p, s and t). These results are in accord with the sensory odor profiles. The intensive negative odor parameters evaluated in "L" and "S" by the panel (figure 1) correlate with off-flavor compounds with higher FD-factors in the olfactograms.

Table 1 summarizes the results of GC-O analysis. The most important aroma compounds were identified by GC-MS and/or reference substances. Some compounds like "baked" (32 min) are still unidentified.

β-damascenone in Potatoes—Due to ongoing studies on the flavor of potatoes and potato products, β-damascenone was identified in several samples after SDE. Although only trace amounts could be detected, the finding of β-damascenone in potatoes, which to our knowledge has not yet been reported elsewhere, is of interest. β-damascenone, a key compound of Bulgarian rose oil (Demole *et al.*, 1970) has a "narcotic-aromatic smell of exotic flowers combined with a heavy note similar to blackcurrant and prune" (Ohloff *et al.*,

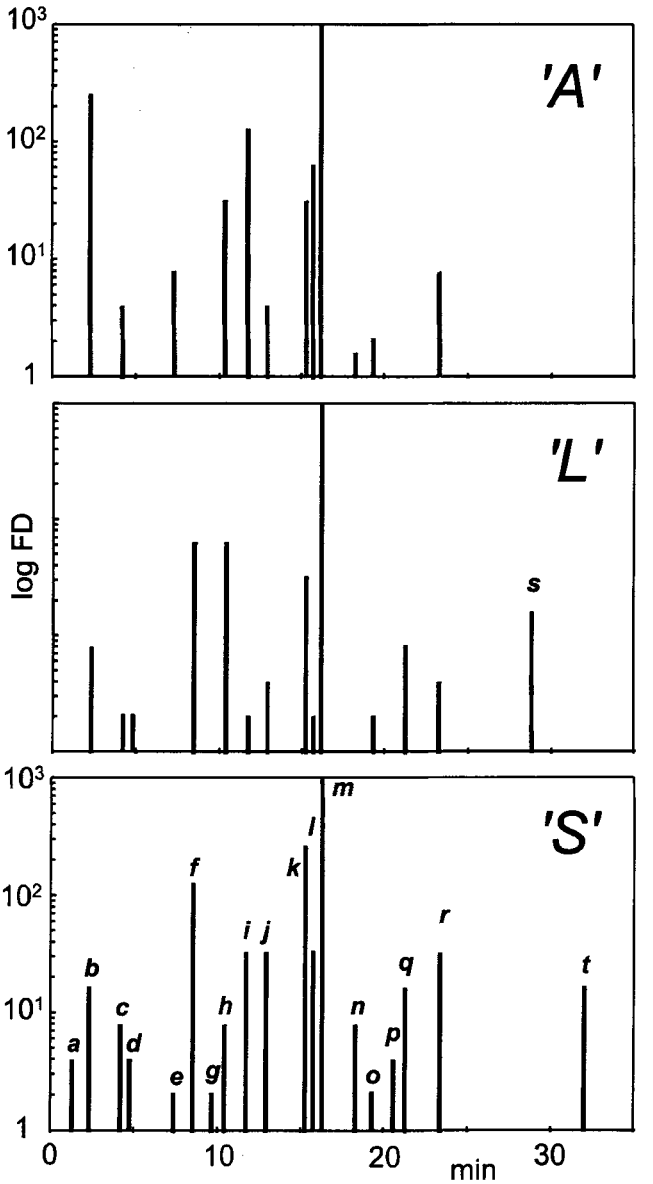

FIGURE 3
Olfactograms of the three different potato genotypes "Adretta" (A), "Likaria" (L) and "St 1,365" (S). The logarithm of the normalized flavor dilution factor (FD-factor) is drawn against the retention time. The FD-factor is the last dilution step, in which a distinct smell impression is perceived. Weak smell impressions with FD-factors below 2 are neglected. The nomenclature of the aroma compounds is equal to table 1.

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TABLE 1—*Results of the AEDA. Basic odorants of the boiled potato aroma.*

no.	RI	substance	sensory quality	identified by [1]
a	1017	unknown	unpleasant	
b	1044	diacetyl	buttery, sweet, caramel	MS, RI
c	1114	hexanal	green	MS, RI
d	1152	(E)-2-pentenal	roasty, rubber, unpleasant	MS, RI
e	1212	2-methylbutanol	unpleasant, sweat	MS, RI
f	1244	2-pentylfuran	unpleasant, green beans, cooked	MS, RI
g	1277	methylpyrazine	nutty, strong	MS, RI
h	1312	octan-2-one	mushroom, earthy	MS, RI
i	1340	2,6-dimethylpyrazine	nutty, warm	MS, RI
j	1383	2-methyl-5-isopropylpyrazine or	nutty, warm, chemical	MS EIC [2]
	1387	2-ethyl-6-methylpyrazine		MS EIC [2]
k	1451	3-ethyl-2,5-dimethylpyrazine	nutty, earthy, herbaceous	RI
l	1459	2-ethyl-3,5-dimethylpyrazine	roasty, coffee-like	RI
m	1474	methional	cooked potato	MS, RI
n	1535	pyrrole	nutty, roasty	MS
o	1566	IST[3], 1-octanol		
p	1591	(E,E)-3,5-octadienone	nutty	MS
q	1609	(E,E)-2,6-nonadienal	fatty, cucumber	MS, RI
r	1674	phenylacetaldehyde	flowery	MS, RI
s	1824	2,4-decadienal	fatty, unpleasant	MS, RI
t	1861	unknown	baked	

[1]the RI of the pyrazines were determined on a wax column by FID and PND
[2]EIC - extracted ion chromatogram
[3]internal standard

1990). Due to its strong odor intensity, β-damascenone (threshold in water: 0.2 ng/l (Buttery *et al.*, 1990)) might contribute to the overall flavor of potatoes in some varieties. β-damascenone was also found in leaves and in sprouts of potato but only after SDE at pH 2.5. This detection of β-damascenone in diverse tissues indicates that these plant parts contain non-volatile β-damascenone precursors derived from carotenoid metabolism, which form through acidic hydrolysis β-damascenone (Isoe *et al.*, 1973; Ohloff *et al.*, 1973; N'f *et al.*, 1990).

In conclusion, the human sensory method employed here was effective in establishing sensory profiles of boiled potatoes. Selected odor parameters are discussed in this paper dealing with aroma: "sweet-like", "earthy", "burnt", "fodder", "untypical", "musty", "fruity", and "typical". Summarizing the results of both methods led to conclusions about essential aroma compounds. Methional, diacetyl and at least five different substituted pyrazines were recognized as character impact compounds. These results are in good agreement with other authors (Salinas *et al.*, 1994; Whitfield and Last, 1991).

All of the three investigated genotypes are characterized by a similar basic pattern of the character impact compounds as shown in this and former papers (Ulrich *et al.*, 1997; Ulrich *et al.*, 1998b). It can be suggested that this pattern - with quantitative modifications - occurs also in other varieties. Additional to these positive aroma compounds, an unknown substance, (E)-2-pentenal, 2-pentylfuran, and at least four different dienals ((E/E)-2,4-heptadienal, (E/E)-2,4-octadienal, (E/Z)-2,6-nonadienal, (E/E)-2,4-decadienal) were found to be off-flavor components. The group of dienals arises from the degradation of multiple unsaturated fatty acids (linolenic acid; Josephson and Lindsay, 1987). The off-flavor components contribute more than the positive ones to the differences in the aroma between genotypes.

Sensory effects created by synergistic and antagonistic interactions of volatile compounds were not taken into account with the GC-O method because quality and quantity of the aroma contribution were estimated with chromatographically separated substances in the effluate of the GC column. Even if compounds like 3-methylbutanal, hexanal, phenylacetaldehyde, (E/E)-2,4-heptadienal, (E/E)-2,4-octadienal, (E/Z)-2,6-nonadienal and β-damascenone are not represented with FD-factors above two in the olfactogram, they could contribute to the overall aroma by interaction with the character impact compounds. Therefore, the substances summarized in table 1 represent the basic aroma of the boiled potato. A simplification of the complex matrix by reduction of the huge number of volatiles to few essential compounds, which can be quantified by chromatography, has to be carried out before developing rapid methods for breeding and quality control. The cleanup method (SDE) employed in this research is not applicable as a rapid method. For instrumental sensory analysis in breeding and quality control programs, simplified methods such as headspace sampling or other approaches, must be developed to analyze off-flavors or aroma precursors.

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