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Effect of Cultivar and Storage Time on the Volatile Flavor Components of Baked Potato

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Tubers of five cultivars of potato were stored at 4 °C for 2, 3, and 8 months and baked in a conventional oven. The flavor compounds from the baked potato flesh were isolated by headspace adsorption onto Tenax and analyzed by gas chromatography−mass spectrometry. On a quantitative basis, compounds derived from lipid and Maillard reaction/sugar degradation dominated the flavor isolates, with sulfur compounds, methoxypyrazines, and terpenes making smaller contributions. Levels of 37 of the >150 detected compounds were monitored in each cultivar with time of storage. Many significant differences were found in levels of individual compounds, compound classes, and total monitored compounds for the individual effects of cultivar and storage time and for their two-way interaction. Differences may be explained by variations in levels of flavor precursors and activities of enzymes mediating flavor compound formation among cultivars and storage times. In addition, differences in agronomic conditions may partly account for variations among cultivars. Overall, of the compounds monitored, those most likely having the greatest flavor impact were 2-isopropyl-3-methyoxypyrazine, 2-isobutyl-3-methoxypyrazine, dimethyl trisulfide, decanal, and 3-methylbutanal, with methylpropanal, 2-methylbutanal, methional, and nonanal also being probable important contributors to flavor.

KEYWORDS: Potato; flavor; aroma; baked potato; cultivar; storage time

INTRODUCTION

The potato, *Solanum tuberosum* L., may be stored following harvest to provide a year-round supply for industry and the domestic consumer. Storage at subambient temperature and controlled humidity slows the metabolic processes in the tuber, thus prolonging shelf life. Nevertheless, changes in tuber composition during storage do occur, including modified profiles of fatty acids (*1*−*4*) and increased levels of sugars (*5*−*7*) and amino acids (*5*, *8*, *9*). Cultivar and cultural conditions may also modify the effect of storage on fatty acids (*1*−*4*), sugars (*10*, *11*), and amino acids (*8*, *12*).

Fatty acids, sugars, and amino acids are the precursors of most of the compounds responsible for the flavor that forms when potato tubers are baked (*13*). The products of the thermal degradation of fatty acids include various aldehydes and ketones, which may contribute fatty, fruity, or floral notes (*14*). The Maillard reaction, involving reducing sugars and amino acids, results in a wide range of compounds including various pyrazines, which are are considered to be key components of baked potato flavor. Strecker degradation of the amino acid methionine yields methional, which possesses a potato-like odor and is another important contributor to baked potato flavor (*13*).

There are reports of intercultural differences in levels of flavor compounds (*15*) and in perceived aroma (*16*) of boiled potatoes. Levels of flavor compounds of baked potato flesh are also reported to vary among cultivars (*17*, *18*). Only two studies could be traced concerning the effect of tuber storage on flavor following cooking. In the first (*19*), tubers stored at 6 °C for 1−2, 4, and 13−14 months were cooked and mashed. Levels of Maillard-derived volatiles were highest after tubers had been stored for 13−14 months, whereas lipid oxidation products were highest after 4 months, although some were masked by Maillard reaction products in the 13−14 month sample. In the second study (*20*), principal component and canonical correlation analyses were applied to a database of several texture and sensory attributes for five potato cultivars, and it was established that tuber storage time (0−38 weeks) was a main factor in the generation of flavor in steam-cooked potatoes.

The aim of the present study was to examine the effects of cultivar and storage time on amounts of selected volatile flavor components of the flesh of potato following baking.

EXPERIMENTAL PROCEDURES

Materials. Potatoes, cultivars Estima, Saxon, Golden Wonder, Kerr's Pink, and Desiree, were grown at different sites in the United Kingdom and were harvested in late September 1996. They were cured for 2 weeks at 12 °C and ambient relative humidity (RH) before the application of storage conditions, which were a temperature of 4 °C

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and 95−98% RH. No sprout inhibitors were used, and there were no visible sprouts at the time of analysis. Tubers were conditioned at 20 °C for 3−5 days, prior to analysis in December 1996, January 1997, and June 1997, corresponding to 2, 3, and 8 months of storage.

Baking Procedure. Individual tubers were washed, dried, and weighed (typical weight = 100−200 g). Tubers were lightly pierced three times with a fork, to a depth of ∼1 cm, and baked in their skins at 190 °C for 1 h in a fan-assisted oven. After baking, they were reweighed and cut in half, and the flesh was scooped out. Flesh from two tubers was combined, and 200 g was weighed into the 1 L sample flask of the headspace collection apparatus. All cultivars were cooked in triplicate, prior to analysis.

Dynamic Headspace Collection. Volatile components were collected on a glass-lined stainless steel trap (105 mm × 3 mm i.d.) containing 85 mg of Tenax TA (SGE, Milton Keynes, U.K.) by passing purified nitrogen gas (120 mL/min) over the cooked potato flesh in the 1 L sample flask of the headspace collection apparatus. The sample flask was held in a water bath at 37 °C, and aroma compounds were collected for 20 min. Prior to collection, 4 μL of a solution of 2-pentanone (internal standard) in methanol (50 mg/mL) was injected onto the Tenax trap. Blanks were performed using an empty sample flask.

Gas Chromatography—Mass Spectrometry (GC-MS). The gas chromatograph was a Hewlett-Packard (Bracknell, U.K.) HP5890 series II instrument, equipped with an SGE CHIS thermal desorption injector. The fused silica capillary column (60 m × 0.25 mm i.d.) was coated with a 0.25 μm film thickness of CP-SIL 8 CB low-bleed (Chrompack, London, U.K.). The gas chromatograph was directly coupled to an HP5972 series mass spectrometer controlled by an HP ChemStation. The trapped volatile components were thermally desorbed onto the GC column by heating the trap at 260 °C for 10 min while the oven was maintained at 0 °C using a subambient accessory on the GC and liquid nitrogen. The column temperature was increased rapidly to 40 °C and held for 8 min. The temperature was then increased to 250 °C at a rate of 4 °C/min and held for 10 min. The helium flow rate was 1 mL/min. The mass spectrometer was operated in the electron impact mode (electron energy = 70 eV), and the ion source temperature was 200 °C. A continuous scan mode was employed with a scan time of 1.9 scans/s over a mass range of 29−400 amu. Compounds were identified by comparison of the sample spectra with those of standards held in the NIST/EPA/NIH Mass Spectral Database (*21*) as well as laboratory databases. Identities were confirmed, when possible, by comparison of linear retention indices (LRI) with those of authentic compounds run under the same conditions and on the same (or similar) stationary phase in the laboratory or published in the literature (*22*, *23*). When both MS and LRI data were consistent with those in the literature or obtained for authentic compounds, identities were considered to be positive. When only MS data were available, identities were considered to be tentative.

Amounts (A) of individual components were expressed as

$$A = (a_1/a_2)(V/M)$$

where a_1 = peak area of sample component, a_2 = peak area of internal standard (2-pentanone), M = mass of potato (kg), and V = volume of nitrogen gas passed over the sample (L).

Statistical Analysis. Quantitative data were analyzed by two-way analysis of variance (ANOVA) using Statistical Analysis System (SAS) version 8 for Windows. For compounds with significant F values ($p < 0.05$), Fisher's least significant difference (LSD) test was applied (two-tailed with $p < 0.05$) to indicate which samples contained significantly different levels of the compound.

RESULTS

More than 150 compounds were detected in this study. Thirty-seven of them were selected on the basis of their positive identification and their presence in most of the five cultivars at each storage time. Also, most had previously been identified in cooked potato, and they represented the different main origins of compounds contributing to the flavor of baked potato flesh, that is, lipids, Maillard reaction and/or sugar degradation, sulfur amino acid degradation, methoxypyrazines, and terpenes. On a quantitative basis, compounds derived from lipids and the Maillard reaction/sugar degradation predominated in all cultivars, the other three categories making minor contributions. Levels of individual compounds, compound classes, and total monitored volatiles generally showed significant differences for the individual variables of cultivar and storage time as well as for their two-way interaction (**Table 1**). More significant effects were observed for cultivar than for storage time. Fewer than half of the monitored compounds showed significant differences for the cultivar × storage time interaction.

Effect of Cultivar. Amounts of each of the monitored compounds in the cultivars were analyzed, disregarding the effect of storage time (**Table 2**). Many statistically significant differences were observed. Cultivars were grown at different locations, and the cultural regimes also varied. Therefore, effects should be considered to be a combination of all these factors. Overall, levels of individual compounds were frequently significantly lower for cv. Kerr's Pink than for at least one other cultivar. The total amount of all monitored compounds was significantly lower for cv. Kerr's Pink and Golden Wonder than for the other cultivars.

Levels of the lipid-derived compounds 2-methylfuran, 2-ethylfuran, 1-oct-en-3-ol, and 2-pentylfuran were significantly higher for cv. Desiree than for at least three other cultivars.

Levels of the Strecker aldehydes, 2-methylbutanal, 3-methylbutanal and phenylacetaldehyde, were significantly higher for cv. Estima, Saxon, and Desiree than for Golden Wonder and Kerr's Pink, whereas methylpropanal was significantly higher in Estima and Desiree. The sugar degradation product, furfural, was significantly higher for Golden Wonder than for the other four cultivars.

Significant intercultivar differences were also observed for sulfur compounds, methoxypyrazines, and terpenes. Desiree gave levels of total and individual sulfur compounds that were significantly higher than those for at least two other cultivars. Amounts of 2-isobutyl-3-methoxypyrazine were also significantly higher for Desiree, whereas Estima gave significantly higher amounts of 2-isopropyl-3-methoxypyrazine. α-Pinene, carene, limonene, α-copaene, and total monitored terpenes were all significantly higher for Estima than for all of the other cultivars.

Effect of Storage Time. Table 3 shows the results of ANOVA of the relative amounts of compounds with storage time (disregarding the effect of cultivar). There was a significant increase in total amounts of compounds between 2 and 3 months and between 3 and 8 months storage.

Total amounts of compounds derived primarily from lipid increased with storage time, and the difference was significant for each storage time interval. However, the behavior of individual lipid-derived compounds varied. Amounts of the lipid-derived aldehydes hexanal, heptanal, nonanal, and decanal all increased significantly between 3 and 8 months. In contrast, other compounds coming from lipid, that is, 2-heptanone, 1-octen-3-ol, and butanedione, were significantly lower after 8 months of storage compared to at least one of the other storage times.

Total levels of Maillard/sugar-derived compounds were significantly higher after 8 months compared to both 2 and 3 months of storage. Methylpropanal, 2-methylbutanal, and 3-methylbutanal all showed a nonsignificant increase between 2 and 3 months, followed by a significant increase between 3 and 8

Table 1. Summary of ANOVA Showing *F* Values and Levels of Significance[a] for the Variables Cultivar, Time, and Cultivar × Time, Using Five Cultivars, Three Storage Times, and Five Replicates

compound by main origin	$\mathrm{LRI}_{\mathrm{exptl}}$[b]	$\mathrm{LRI}_{\mathrm{lit.}}$[c]	cultivar	time	cultivar × time
lipids					
butanedione[e–g]	616	612	3.95**	64.16***	1.53ns
2-methylfuran[f]	629	633	5.67***	2.13ns	1.13ns
2-ethylfuran[d–f]	704	701	30.26***	13.76***	2.63*
pentanal[d–g]	708	*707*	1.05ns	2.72ns	1.23ns
hexanal[d–g]	803	*809*	3.55*	11.93***	2.06ns
2-heptanone[e–g]	900	*898*	6.66***	10.64***	3.74***
heptanal[d–g]	911	*913*	7.56***	14.20***	1.66ns
benzaldehyde[d–g]	982	*983*	8.14***	4.72*	4.73***
1-octen-3-ol[d–f]	991	*986*	10.36***	13.55***	3.03**
2-pentylfuran[d–g]	993	*994*	27.46***	5.03*	0.33ns
nonanal[e–g]	1114	*1118*	5.93***	23.89***	2.66*
decanal[e–g]	1216	1217	3.96**	32.59***	3.32**
total			11.87***	12.02***	2.72*
sugar degradation and/or Maillard reaction not involving sulfur amino acids					
methylpropanal[d–g]			18.26***	23.15***	6.85***
3-methylbutanal[d–g]	671	*667*	10.63***	51.63***	7.11***
2-methylbutanal[d–g]	679	*672*	18.65***	26.19***	6.28***
2,3-pentanedione[e–g]	709	*698*	0.82ns	5.55**	2.02ns
3-methyl-1-butanol[d–g]	743	*740*	28.33***	17.23***	2.09ns
2-methyl-1-butanol[d–g]	746	*744*	28.66***	3.59*	0.69ns
pyridine[e–g]	754	*756*	15.03***	3.49*	2.07ns
methylpyrazine[e–g]	838	*837*	1.75ns	1.44ns	1.26ns
furfural[e–g]	847	*848*	17.34***	17.72***	1.93ns
2,5(6)-dimethylpyrazine[e–g]	926	*925*	0.75ns	0.85ns	1.60ns
2-ethyl-3-methylpyrazine[f]	1016	1016	0.44ns	11.23***	0.79ns
phenylacetaldehyde[d–g]	1065	1052	12.36***	8.35***	4.10***
total			15.72***	24.55***	6.28***
sulfur amino acids					
dimethyl disulfide[e–g]	750	756	3.85**	1.31ns	0.70ns
3-(methylthio)propanal (methional)[e–g]	925	911	27.55***	11.13***	2.57*
dimethyl trisufide[e–g]	989	*984*	4.68*	0.28ns	0.83ns
dimethyl tetrasulfide[f,g]	1252	1251	5.33**	1.85ns	0.84ns
total			9.20***	0.10ns	1.10ns
methoxypyrazines					
2-isopropyl-3-methoxypyrazine[d–f]	1098	1097	10.78***	4.11*	2.89*
2-isobutyl-3-methoxypyrazine[d–f]	1188	1186	11.47***	2.32ns	1.33ns
total			9.41***	4.04*	1.95ns
terpenes					
α-pinene[e,f]	938	*937*	10.81***	18.75***	4.78***
3-carene[e,f]	1016	1013	5.80***	1.39ns	1.75ns
p-cymene	1024	1026	7.75***	9.55***	2.29*
D-limonene[e–g]	1038	*1040*	8.21***	47.57***	4.60***
β-phellandrene[f]	1043	1034	3.39*	4.91*	1.00ns
terpinolene	1094	1093	3.26*	16.32***	3.02**
α-copaene[f,g]	1392	1390	50.30***	10.03***	6.13***
total			15.64***	44.45***	5.27***
total of all monitored volatiles			23.47***	26.76***	2.49*

[a] ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; ns, $p > 0.05$. [b] Calculated LRI values for identified components. [c] LRI obtained for authentic compounds analyzed on the same GC column or from the literature (*22*, *23*). Values for authentic compounds are in italics. [d] Identified in raw potatoes (*24*). [e] Identified in boiled potatoes (*16*, *25–27*). [f] Identified in baked potatoes (*17*, *18*, *24*). [g] Identified in French-fried potatoes (*24*, *28*, *29*).

months. Levels of phenylacetaldehyde and furfural increased significantly between 2 and 3 months and then remained constant between 3 and 8 months.

Methional was the only sulfur compound that showed a significant storage time effect, amounts decreasing between 3 and 8 months.

Amounts for individual terpenes (except 3-carene) were significantly higher after 3 months compared to both of the other storage times.

Effect of Cultivar and Storage Time. The effects of any interactions between cultivar and storage time on levels of compounds are given in **Table 4**. Storage effects varied with cultivar. Total amounts of all monitored compounds were lowest for Kerr's Pink and highest for Estima and Desiree at all storage times.

Between 2 and 3 months, significant increases were observed for the lipid-derived compounds 1-octen-3-ol (Desiree and Estima) and benzaldehyde (Saxon). Between 3 and 8 months, decanal increased significantly for Saxon, Estima, and Golden Wonder. Over the same time interval, benzaldehyde decreased significantly for Saxon and Desiree but showed a significant increase for Golden Wonder.

Table 2. Least Significant Differences (LSD)[a] and Mean Relative Amounts[b] of Volatile Components among Cultivars (Means of Three Storage Times and Five Replicates)

compound by main origin	LSD	Saxon	Desiree	Estima	Golden Wonder	Kerr's Pink
lipids						
butanedione	173	690a	524bc	740b	596ab	449a
2-methylfuran	61	102b	130b	57a	1a	23a
2-ethylfuran	29	64b	161c	148c	32a	49ab
pentanal		148	154	170	95	104
hexanal	440	1123bc	1264c	1388c	555a	814ab
2-heptanone	13	1a	12a	28b	10a	
heptanal	38	116b	165c	117b	86ab	77a
benzaldehyde	47	247bc	253c	203b	222bc	144a
1-octen-3-ol	84	18a	157bc	218c	88ab	42a
2-pentylfuran	134	145a	665c	402b	137a	100a
nonanal	251	571bc	782c	513b	439ab	241a
decanal	324	665b	826b	694b	602b	241a
total	977	3890b	5093c	4678c	2863a	2285a
sugar degradation and/or Maillard reaction not involving sulfur amino acids						
methylpropanal	258	621a	1264b	1276b	385a	518a
3-methylbutanal	355	1547b	2132c	1783bc	956a	1189a
2-methylbutanal	582	2386b	3164c	2682bc	917a	1189a
2,3-pentanedione		141	192	123	112	125
3-methyl-1-butanol	104	127a	88a	475c	334b	45a
2-methyl-1-butanol	172	107a	71a	811c	286b	37a
pyridine	45	82b	43ab	110c	189d	20a
methylpyrazine		12	19	4	2	3
furfural	102	314bc	356c	233ab	562d	160a
2,5(6)-dimethylpyrazine		1		3	1	1
2-ethyl-3-methylpyrazine		4	5	4	4	3
phenylacetaldehyde	40	138b	119b	105b	49a	40a
total	1326	5481b	7483c	7610c	3798a	3328a
sulfur amino acids						
dimethyl disulfide	66	9a	111b		44a	3a
3-(methylthio)propanal (methional)	42	175c	147bc	112b	14a	29a
dimethyl trisulfide	63	56ab	119b	15a	36a	
dimethyl tetrasulfide	8	4ab	13b	1a	2a	1a
total	141	244b	390c	128ab	96a	32a
methoxypyrazines						
2-isopropyl-3-methoxypyrazine	11		1a	28b		2a
2-isobutyl-3-methoxypyrazine	19	1a	47b	8a		2a
total	23	1a	48b	36b		4a
terpenes						
α-pinene	11	20a	21a	42b	13a	20a
3-carene	11	4a	7a	19b	1a	
p-cymene	4	9bc	12c	4a	6ab	4a
D-limonene	71	81a	96a	224b	68a	93a
β-phellandrene	12	5ab	18c	15bc	6ab	3a
terpinolene	3	3ab	6b	2a	4ab	1a
α-copaene	18	54b	4a	99c	5a	5a
total	96	176a	164a	405b	102a	127a
total of all monitored volatiles	1872	9791b	13148c	12858c	6858a	5776a

[a] Fisher's least significant difference. [b] Amounts of components are quoted in terms of GC peak area units (see Experimental Procedures). Figures quoted are the means of five replicate analyses. Means with different letters within a row are significantly different ($p < 0.05$).

Total amounts of compounds coming from the Maillard reaction and/or sugar degradation increased significantly between 3 and 8 months for Desiree, Estima, and Kerr's Pink. Between 2 and 3 months, phenylacetaldehyde increased significantly for Saxon and Desiree. The Strecker aldehydes of valine, isoleucine, leucine, and phenylalanine showed significant increases between 3 and 8 months, that is, methylpropanal (Desiree and Kerr's Pink), 3-methylbutanal (Desiree, Estima, Golden Wonder, and Kerr's Pink), 2-methylbutanal (Desiree, Estima, and Kerr's Pink), and phenylacetaldehyde (Saxon and Golden Wonder).

Amounts of seven terpenes were monitored. Total levels increased significantly between 2 and 3 months for Estima, Golden Wonder, and Kerr's Pink and decreased significantly between 3 and 8 months for all cultivars. Limonene increased significantly between 2 and 3 months for Saxon, Estima, Golden Wonder, and Kerr's Pink and decreased significantly between 3 and 8 months for all cultivars.

Relative Aroma Impact Values (RAVs). Table 5 gives the RAVs of 21 of the monitored compounds; the RAV of a compound is defined as its relative GC peak area (see **Table 1**) divided by its odor threshold value in water (micrograms per

Table 3. Least Significant Differences (LSD)[a] and Mean Relative Amounts[b] of Volatile Components among Storage Times (Means of Five Cultivars and Five Replicates)

		storage time		
compound by main origin	LSD	2 months	3 months	8 months
lipids				
butanedione	134	766b	908c	126a
2-methylfuran		46	48	94
2-ethylfuran	23	67a	122b	83a
pentanal		93	154	157
hexanal	341	681a	857a	1548b
2-heptanone	10	22b	44a	5a
heptanal	30	85a	88a	163b
benzaldehyde	36	204a	246b	192a
1-octen-3-ol	65	125b	184b	4a
2-pentylfuran	104	272a	381b	217a
nonanal	195	239a	353a	935b
decanal	251	173a	407a	1236b
total	758	2772a	3752b	4761c
sugar degradation and/or Maillard reaction not involving sulfur amino acids				
methylpropanal	200	538a	661a	1239b
3-methylbutanal	275	956a	1208a	23398b
2-methylbutanal	451	1377a	1748a	3078b
2,3-pentanedione	54	95a	130a	191b
3-methyl-1-butanol	81	313b	261b	67a
2-methyl-1-butanol	133	356b	301b	150a
pyridine	32	63a	103b	99b
methylpyrazine		3	9	12
furfural	79	193a	390b	391b
2,5(6)-dimethylpyrazine		1	1	2
2-ethyl-3-methylpyrazine	4	4a	9b	
phenylacetaldehyde	31	55a	113b	103b
total	1028	3937a	4935a	7730b
sulfur amino acids				
dimethyl disulfide		29	13	27
3-(methylthio)propanal (methional)	32	107b	130b	50a
dimethyl trisulfide		39	40	56
dimethyl tetrasulfide		6	6	1
total		181	189	163
methoxypyrazines				
2-isopropyl-3-methoxypyrazine	9	2a	13b	3a
2-isobutyl-3-methoxypyrazine		14	19	2
total	18	16ab	32b	5a
terpenes				
α-pinene	9	27b	36c	8a
3-carene		10	7	3
p-cymene	3	6a	11b	4a
D-limonene	55	51a	263b	23a
β-phellandrene	9	10ab	17b	2a
terpinolene	3	2a	7b	
α-copaene	14	30a	50b	20a
total	74	135b	390c	59a
total of all monitored volatiles	1451	7041a	9298b	12719c

[a] Fisher's least significant difference. [b] Amounts of components are quoted in terms of GC peak area units (see Experimental Procedures). Figures quoted are the means of five replicate analyses. Means with different letters within a row are significantly different ($p < 0.05$).

liter). Compound selection was based on the availability in the literature of odor threshold values (OTVs) in water of the standard compounds and a RAV of >1 in at least one cultivar. The two methoxypyrazines, dimethyl trisulfide, decanal, and 3-methylbutanal would be expected to have the greatest impact on aroma because they possessed RAVs of >10000 in at least one sample. Methylpropanal, 2-methylbutanal, methional, and nonanal possessed RAVs of between 1000 and 10000 and would also be expected to be important contributors to aroma.

DISCUSSION

The results from this study illustrate the effect of both cultivar and tuber storage time on the relative amounts of selected volatile compounds associated with the flavor of baked potato flesh. The main flavor precursors in the raw tuber are sugars (*17*, *32*), amino acids (*17*, *33*), and lipids (mainly polyunsaturated fatty acids) (*34*). They are formed as a result of metabolic processes in the tuber, their production being controlled by enzymes and their synthesis varying with cultivar and environ-

Table 4. Least Significant Differences (LSD)[a] and Mean Relative Amounts[b] of Volatile Components among Five Cultivars and Three Storage Times

compound by main origin	LSD	Saxon			Desiree			Estima			Golden Wonder			Kerr's Pink		
		2 months	3 months	8 months	2 months	3 months	8 months	2 months	3 months	8 months	2 months	3 months	8 months	2 months	3 months	8 months
lipids																
butanedione	299	876d	1195e		633cd	888d	51a	870d	928d	422bc	763d	868d	158ab	686cd	662cd	
2-methylfuran	105	46ab	95abcde	165de	154cde	64abcd	173e	2a	56abc	113bcde	1a			26ab	23ab	20ab
2-ethylfuran	51	37ab	124cde	29ab	106cd	166ef	211f	128de	192f	123cde	27ab	51ab	19a	38ab	75bc	34ab
pentanal		95	216	132	104	209	150	87	121	301	84	96	106	92	126	94
hexanal	761	759ab	981abc	1628c	826ab	1287bc	1680c	663ab	789ab	2712d	487a	403a	774ab	669ab	825ab	947abc
2-heptanone	22		4ab		22abc	13abc		61d		23bc	28c	1a				
heptanal	67	65a	94ab	187c	172c	157bc	165c	62a	86a	202c	50a	53a	156bc	74a	52a	104ab
benzaldehyde	81	198bcd	359f	185abcd	265de	309ef	185abcd	205bcd	235cde	170abc	201bcd	159abc	306ef	152ab	167abc	114a
1-octen-3-ol	146	16a	38a		158ab	314cd		232bc	422d		149ab	114ab		72a	33a	22a
2-pentylfuran	232	121a	250ab	65a	611c	804d	580c	420bc	520c	266ab	125a	165a	121a	81a	165a	55a
nonanal	434	142a	40ab	1168e	705bcd	857cde	784bcde	93a	242a	1205e	72a	159a	1085de	183a	108a	433abc
decanal	560	91a	465ab	1439de	558abc	1048cd	871bcd	69a	309a	1703e	63a	115a	1627e	82a	100a	541abc
total	1692	2447ab	4224cd	4999de	4315cd	6115ef	4848de	289abc	3901bcd	7242f	2051a	2185a	4352cd	2156a	2335ab	2364ab
sugar degradation and/or Maillard reaction not involving sulfur amino acids																
methylpropanal	447	435abc	731bcde	699abcd	456abc	764cdef	2571h	1149efg	1186fg	1492g	320ab	363abc	471abc	330abc	260a	964def
3-methylbutanal	615	1218abcd	1730de	1693de	880abc	1339bcd	4177g	1378cd	1447cd	2524f	694a	755ab	1420cd	622a	768ab	2176ef
2-methylbutanal	1008	2012bc	2771cd	2374c	1348ab	2134bc	6012e	2167bc	2218bc	3661d	683a	856a	1214ab	676a	760a	2131bc
2,3-pentanedione	120	110a	170a	143a	71a	131a	373b	100a	141a	130a	88a	111a	139a	107a	97a	170a
3-methyl-1-butanol	180	213ab	168ab		134a	130a		562d	529d	333bc	575d	427cd		82a	51a	
2-methyl-1-butanol	298	190abc	130ab		134ab	79ab		800e	883e	751de	483cd	375bc		71a	40a	
pyridine	78	61ab	112bc	73ab	59ab	69ab		55ab	114bc	162cd	117bc	203d	247e	25a	20a	14a
methylpyrazine		7	15	12	5	10	42	8	3		2	5		1	7	
furfural	176	200abc	485fg	256abcd	178ab	418def	471efg	115a	296bcde	288abcd	355cdef	631gh	699h	118a	122ab	239abc
2,5(6)-dimethyl-pyrazine				3				1		8	1	3			4	
2-ethyl-3-methyl-pyrazine	8	7a	7a		2a	14b		6a	8a		3a	8a			8a	
phenylacetaldehyde	64	83abcd	234f	97bcde	74abc	155e	129cde	69abc	143de	103bcde	21a		125cde	28a	32a	59ab
total	2296	4538bcd	6554de	5350bcde	3342ab	5242bcde	13776g	6402de	6972e	9456f	3340ab	3736abc	4315abcd	2062a	2169a	5753cde
sulfur amino acids																
dimethyl disulfide		5		21	140	64	128						132		3	6
3-(methylthio)propanal (methional)	72	204gh	266h	54abcde	155bcde	202gh	155fg	124ef	119def	93cdef	15ab	12a	16ab	37abc	50abcd	1a
dimethyl trisulfide		92	70	6	103	130	123			46		1	106			
dimethyl tetrasulfide	14	5a	6ab	1a	21c	19bc		1a			3a	2a			1a	
total	245	307cde	342de	82abc	419e	415e	336de	125abcd	119abcd	138abcd	18ab	16ab	253bcde	37ab	53ab	7a
methoxypyrazines																
2-isopropyl-3-methoxypyrazine	19					3a		10a	57b	17a					4a	
2-isobutyl-3-methoxy-pyrazine	33	1a			64b	68b	9a	3a	21a	2a				1a	5a	
total	41	1a			64b	71b	9a	12a	77b	19a				2a	10a	
terpenes																
α-pinene	19	21abcd	31cde	6a	38de	25bcde		42e	79f	5a	16abc	15abc	9ab	15abc	28cde	18abc
3-carene	18	5a		8ab	17abc		5a	24bc	34c		4a					
p-cymene	8	7a	16bc	4a	10ab	21c	5a		7a	4a	7a	10ab	2a	4a	2a	5a
D-limonene	123	56ab	184cd	3a	75abc	188cd	24a	67abc	557e	50ab	17a	170bcd	15a	42a	214d	24a
β-phellandrene	20	6ab	8ab	1a	31d	24bcd		9abc	28cd	8ab	2a	15abcd		1a	9abc	
terpinolene	6	5ab	2a		2a	15c		1a	5ab		1a	10bc			3a	
α-copaene	31	73b	88b	2a	7a	5a		61b	147c	89b		3a	11a	7a	8a	
total	199	173abcde	330e	24a	179abcde	278de	34a	204bcde	857f	155adbd	47ab	223cde	37a	70abc	263de	47ab
total of all monitored volatiles	3242	7465abcd	11450ef	10456def	8319bcde	12122f	19002g	9636def	11927f	17010g	5457ab	6160abc	8957cdef	4326a	4330a	8171bcd

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[a] Fisher's least significant difference. [b] Amounts of components are quoted in terms of GC peak units (see Experimental Procedures). Figures quoted are the means of five replicate analyses. Means with different letters within a row are significantly different ($p < 0.05$).

mental conditions (*5*−*9*, *35*−*38*). During baking, they react to give the majority of the monitored compounds, that is, those formed by lipid degradation or the Maillard reaction/sugar degradation. The monitored sulfur compounds may also form during baking, as a result of the degradation of sulfur amino acids. In contrast, the methoxypyrazines (*39*, *40*) and terpenes (*41*, *42*) are themselves products of potato metabolism. The predominance of compounds derived from lipid and the Maillard reaction is in line with previous flavor studies on baked potato flesh (*17*, *18*).

Lipid-Derived Compounds. Compounds coming from lipids represented 26−52% of the total yield of the 37 monitored compounds. Lipids account for only 0.8−1.3 mg/g of dry fresh weight (*34*), but the relatively reactive polyunsaturated fatty acids, linoleic and linolenic acid, which degrade to yield a wide range of volatile compounds, together account for 70−75% of the total fatty acids (*34*). Differences in lipid enzyme activities or fatty acid profiles could account for the intercultivar and storage time variations in levels of lipid-derived flavor compounds observed in this study.

The lipid enzymes, lipolytic acyl hydrolase (LAH) and lipoxygenase (LOX), are active during the storage of potato tubers (*35*). Variations in their activities have been reported among cultivars (*36*, *37*) and with storage time, with LAH and

Table 5. Relative Aroma Values (RAVs)[a] of Selected Volatile Compounds Identified in Five Cultivars of Potato after Storage of Tubers for 2, 3, and 8 Months and Baking

		Estima			Saxon			Golden Wonder			Kerr's Pink			Desiree		
compound by main origin	OTV[b]	2 months	3 months	8 months	2 months	3 months	8 months	2 months	3 months	8 months	2 months	3 months	8 months	2 months	3 months	8 months
2-isopropyl-3-methoxy-pyrazine	0.002	5000	28500	8500							500	2000			1500	
2-isobutyl-3-methoxy-pyrazine	0.002	1500	10500	1000	500						500	2500		32000	34000	
dimethyl trisufide	0.01			4600	9200	7000	600		100	10600				10300	13000	12300
decanal	0.1	690	3090	17040	910	4650	14390	620	1150	16270	820	1000	1541	5580	10480	8710
3-methylbutanal	0.2	6890	7235	12620	6090	8650	8465	3470	3775	7100	3115	3840	10880	4400	6695	20885
dimethyl disulfide	0.2				30		105			660		15	30	700	320	640
3-(methylthio)propanal	0.2	620	595	465	1020	1330	270	75	60	80	185	245	5	775	1010	420
methylpropanal	0.9	1277	1318	1658	483	812	777	356	403	523	367	289	1071	507	849	2857
nonanal	1	93	242	1205	142	401	1168	72	159	1085	183	108	433	705	857	784
1-octen-3-ol	1.4	166	301		11	27		106	81		51	24	16	113	224	
heptanal	3	304	21	67	22	31	62	17	18	52	25	17	35	57	52	55
2-methyl butanal	3	722	740	1220	671	924	791	228	285	405	225	253	710	449	711	2004
phenylacetaldehyde	4	17	36	26	21	59	24	5		31	7	8	15	19	39	32
hexanal	4.5	147	175	603	169	218	362	108	90	172	149	183	210	184	286	373
2-pentylfuran	6	70	87	44	20	42	11	21	28	20	14	28	9	102	134	97
butanedione	7	124	133	60	125	171		109	124	23	98	95		90	127	7
pentanal	12	7	10	25	8	18	11	7	8	9	8	11	8	9	17	13
2,3-pentanedione	20	5	7	7	6	9	7	4	6	7	5	5	9	4	7	19
3-methyl-1-butanol	250	2	2	1	1	1		2	2					1	1	
2-methyl-1-butanol	250	3	4	3	1	1		2	2					1		
benzaldehyde	350	1	1		1	1	1	1		1				1	1	1

[a] RAVs calculated by dividing the amount of each compound (see Experimental Procedures) by the odor threshold value (OTV). [b] Odor threshold value in water (*13*, *30*, *31*).

LOX activities of several cultivars increasing at some point during storage for up to 30 weeks at 8 °C (*38*).

Two studies report no significant differences in profiles of fatty acids among various potato cultivars (*3*, *34*), whereas a significant difference in levels of total fatty acids among cultivars was reported by Cotfugo and Lunsetter (*2*). Evidence for the effect of storage on fatty acid profiles is stronger. When cells are exposed to temperatures that are not optimum for their growth, they may attempt to adapt, to maintain the physical state and function of the cell membrane, by varying the number of cis double bonds in membrane lipid fatty acids (*43*). The fatty acid profile of potato tubers can change during storage, the precise effect differing with cultivar and storage conditions (*1*−*4*). Storage increases the level of linolenic acid in some cultivars at the expense of linoleic acid, whereas the linolenic acid/linoleic acid ratio is unaffected in other cultivars stored under the same conditions (*1*, *3*). Total fatty acid levels also increase on storage (*2*, *4*). The reported varying effects of cultivar and storage on fatty acids are in line with the effects of these variables on lipid-derived flavor compounds observed in this study.

Maillard/Sugar-Derived Compounds. The Maillard reaction/sugar degradation was also a major source of components contributing to the flavor of baked potato flesh, accounting for 40−73% of the total amount of the 37 monitored compounds. The Maillard reaction takes place when compounds possessing a carbonyl group, typically reducing sugars, react with components with a free amino group, such as amino acids. The Strecker degradation of amino acids takes place during the Maillard reaction, and the resulting Strecker aldehydes contribute to flavor. The significantly higher levels of methylpropanal, 2- and 3-methylbutanal, and phenylacetaldehyde in Estima, Saxon, and Desiree, compared to Golden Wonder and Kerr's Pink, and the significantly different levels among cultivars of the sugar degradation compound furfural (**Tables 2** and **4**) are presumably due to variations in the levels of their flavor precursors, that is, sugars and amino acids, among cultivars. Statistically significant differences for furfural and 2- and 3-methylbutanal among cultivars grown under the same conditions at the same location were observed by Duckham et al. (*18*), indicating that cultivar accounts for at least some of the variation observed in the current study, although location and agronomic factors may also play a role (*8*, *10*−*12*).

There is general agreement that levels of sugars (*5*−*7*) and free amino acids (*5*, *8*, *9*) in potato tubers increase during storage. Increases in levels of both these groups of flavor precursors during storage could contribute to the higher levels of Maillard/sugar-derived products observed at the longer storage times (**Tables 3** and **4**), in line with Salinas et al. (*19*), who reported higher levels of Maillard products in mashed potato prepared from tubers that had been stored for 13−14 months than in tubers stored for either 1−2 or 4 months.

Sulfur Compounds. The observed differences in levels of sulfur compounds with cultivar and storage time may be attributed to variations in levels of reducing sugars and sulfur amino acids (methionine and cysteine). The combined effect of cultivar and agronomic factors had a much greater influence on levels of sulfur compounds in the current study (**Table 2**) than did the effect of cultivar (all cultivars grown at the same location) in the investigation of Duckham et al. (*18*). In that study, levels of dimethyl trisulfide were significantly higher in Desiree and Estima than in the other nine cultivars, but no significant difference was found for the other sulfur compounds identified. It is suggested that agronomic factors, for example, sulfur fertilizer application rates, may account at least in part for the differences observed here.

Methoxypyrazines. Methoxypyrazines may be synthesized by the potato tuber or by soil bacteria, followed by their subsequent absorption by the tuber (*44*). The significantly higher levels of 2-isobutyl-3-methyoxypyrazine in Desiree and of 2-isopropyl-3-methyoxypyrazine in Estima indicate that cultivar and/or agronomic factors do affect the formation of these compounds. Because the different cultivars were grown at different sites, it is not possible to ascertain which effect was more important. Intercultivar differences in levels of these two methoxypyrazines have been reported previously when tubers were grown at the same location (*18*). There were no significant storage time effects on methoxypyrazine formation; presumably their formation was prevented at the storage temperature (4 °C) used for this study.

Terpenes. Terpenes are synthesized from acetyl coenzyme A (*45*, *46*), and they have been used to distinguish among grape cultivars (*46*). In the current study, Estima could be distinguished from the other four cultivars on the basis of its significantly higher levels of α-pinene, carene, limonene, and α-copaene. Differences among cultivars in levels of terpenes in baked potato flesh have been reported previously (*18*). When the effect of storage time was considered in the current study, the significantly higher levels of five terpenes observed after 3 months, compared to the other storage times, suggests that it may be possible to manipulate amounts of these flavor compounds in the raw tuber by control of storage time.

Total Compounds. Total amounts of monitored flavor compounds were significantly higher in Estima and Desiree than in Saxon, which in turn was significantly higher compared to Golden Wonder and Kerr's Pink. These differences presumably reflect differences in metabolic processes or agronomic factors. The effect of storage time was to significantly increase total amounts of compounds over both time intervals, presumably due to mobilization of the major flavor precursors and activation of lipid enzymes during storage, as discussed above. This is in line with the results of a study of the effect of tuber age on the volatile components of mashed potato (*19*). Also, Vainionpää et al. (*20*) established that storage time and cultivar both affect the sensory flavor properties of boiled potato. An overall increase in levels of monitored compounds on storage implies an increase in the strength of the aroma. However, compounds do not necessarily give the same odor at different concentrations. If levels of some compounds increase relatively more than others, the quality of the baked potato aroma will be affected.

Contribution of Compounds to Aroma. RAVs are arbitrary but nevertheless provide an indication of the contribution of each listed compound to aroma in the cultivars examined. Unlike odor unit values, RAVs do not indicate whether a compound is present at above or below its odor threshold value.

Due to their extremely low odor threshold values (*31*), the two methoxypyrazines had high RAVs in samples in which they were identified at low levels and will contribute musty, earthy notes. Because these compounds possess such low odor threshold values, they may also be sensorially important in samples for which the level is below the detection limit. Coleman and Ho (*47*) were the first to identify 2-isopropyl-3-methoxypyrazine in baked potato.

Of all of the compounds monitored, 3-methylbutanal was one of the most abundant, and this accounts for RAVs of the same order of magnitude as those of the methoxypyrazines. This compound and 2-methylbutanal (also listed in **Table 5**) possess fruity notes (*48*) and were described as "malty" by gas chromatography−olfactometry (GC-O) of a boiled potato isolate (*27*).

RAVs for decanal ranged from 620 to 17040. This compound, together with the other alkanals listed in **Table 5**, will contribute fruity, fatty, and floral notes (*14*).

Methional is a key contributor to the flavor of baked potato (*13*, *39*, *49*) and had RAVs in the range of 5−1300. Dimethyl trisulfide was not identified in some samples, although RAVs were as high as 13000 in others.

In conclusion, the flavor of baked potato varies according to cultivar, agronomic factors, and tuber storage conditions. It is suggested that each of these variables affects levels of flavor precursors and activities of enzymes that mediate the formation of flavor compounds. The variables may be manipulated to yield tubers with different aromas following baking.

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