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Headspace Volatiles and Sensory Characteristics of Earthy, Musty Flavoured Potatoes

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ABSTRACT

Sensory and instrumental flavour characteristics of commercially stored Russet Burbank potatoes sprout-inhibited with two commercial formulations of CIPC, and with maleic hydrazide were determined. Sensory evaluation was carried out using descriptive and multiple comparison analyses. For instrumental assessment, GC–MS analysis of headspace volatiles concentrated on Tenax GC was employed. Results from both methods of flavour evaluation revealed that potatoes treated with a commercial formulation of CIPC, which contained HiSol 10 as a carrier, possessed distinct earthy, musty, potato bin-like aromas and yielded headspace richer in benzene derivatives. Potatoes not sprout-inhibited and potatoes sprout-inhibited with CIPC in methanol and with maleic hydrazide possessed pleasant, potato-like flavour characteristics.

INTRODUCTION

In 1983–87, significant quantities of frozen French fries produced from Russet Burbank potatoes grown and stored in western Canada were found to possess a musty, earthy off-flavour and could not be marketed. Preliminary investigations carried out by industry indicated that no identifiable treatment could be associated with the off-flavour. Recently, field and storage records from producers and sensory records from processors, for over 95% of the 1987 Manitoba potato crop, were collected. The results of these surveys revealed that most of the off-flavour potatoes were sprout inhibited with a commercial formulation of isopropyl-*N*-(3-chlorophenyl) carbamate (CIPC, chloropropham). CIPC, however, has

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been used as a sprout suppressant on potatoes for over three decades without a reported effect on potato flavour (Marth & Schultz, 1952; Van Vliet & Sparenberg, 1970; Filmer & Land, 1978; Heikes, 1985; Coxon & Filmer, 1985; Boyd & Duncan, 1986). Commercial solutions of CIPC, which are generally applied to potatoes through the ventilation system, contain the active ingredient CIPC, and one or more organic solvents as the carrier. The most common carriers include propylene glycol, methanol and HiSol 10 which is a mixture of aromatic hydrocarbons.

The musty, earthy flavour in potatoes is reported to be due to the presence of 2-methoxypyrazines, 3-isopropyl and 3-ethyl (Buttery & Ling, 1973; Nursten & Sheen, 1974). The flavour thresholds in potatoes for these two compounds have been reported to be in the order of 10 ppt and 1 ppt, respectively. Murray *et al.* (1976) have suggested that these methoxypyrazines derive from the amino acids valine and 2-aminobutyric acid, respectively, by the mechanism of amidation of the amino acid followed by condensation with an alpha, beta-dicarbonyl compound to form a 2-hydroxypyrazine which is methylated to the methoxypyrazine. Other compounds associated with earthy, musty flavours of foods are geosmin, 2-methylisoborneol, 2,3,6- and 2,3,4,6-trichloroanisole, mucidone and cadinal (Curtis *et al.*, 1972; Guadagni & Buttery, 1978; Gerber, 1979). However, to our knowledge none of these compounds has been found in potatoes.

The present study was, therefore, undertaken to investigate sensory and instrumental flavour characteristics of commercially stored Russet Burbank potatoes, with the objective of determining the cause for the occurrence of a musty, earthy off-flavour in some of the potatoes.

MATERIALS AND METHODS

Raw material

Russet Burbank potatoes grown and stored commercially in southern Manitoba were used. Samples were taken from 16 potato storage bins, each containing 500–2500 tonnes of potatoes, belonging to 14 separate producers. Of the 16 storage bins, two bins contained potatoes not treated with any sprout inhibitor, three bins were treated with a commercial formulation of CIPC in methanol (CIPC-840), nine bins were treated with a commercial formulation of CIPC in propylene glycol and HiSol 10 (CIPC-500H) and two bins contained potatoes treated with maleic hydrazide. CIPC formulations were applied as aerosol through the ventilation system by experienced industrial applicators. Maleic hydrazide was applied as a spray by the producer at recommended rates to the potato foliage prior to harvest.

All potatoes were at $10 \pm 2°C$ and $85 \pm 5\%$ relative humidity for 3 months prior to sampling and analysis.

Sensory evaluation

Description of off-flavour characteristics and the magnitude of flavour variation from the ideal, typical, fresh potato-like flavour were obtained by descriptive analysis with linear scaling (Larmond, 1977). Flavour differences and desirability of flavour differences as compared to a standard sample of potatoes with a pleasant potato-like flavour and which had been given the best score by the panel, were measured using a modified version of the multiple comparison test of Mahoney *et al.* (1957). For this test, instead of the numerical scores with verbal descriptions, a 10 cm horizontal line was used. This modification to the multiple comparison test was made on account of the superiority of graphical scales over numerical scorings (ASTM, 1968; Barytko-Pikielna, 1975).

For sample presentation sequence, four samples, four replications completely balanced block design was chosen (Sidel & Stone, 1976) where each judge tested each sample in all possible serving orders an equal number of times. To monitor discriminatory ability of the judges, the control sample was presented as a marked reference and as a coded sample at each sitting.

The samples were presented in uniform, covered Petri dishes, which were coded by three digit numbers. No strict tasting or sniffing techniques were introduced. Judges were asked to make an initial comparison of odour and then taste for total flavour by mouth impression. Between testings, judges used deionized water to rinse the mouth of residual stimuli and lessen the adaptation effects (O'Mahony, 1979). Judges maintained their own intersample rinsing regime to clean the mouth yet not cause memory loss of prior taste (O'Mahony & Goldstein, 1987). There was no instruction in regard to swallowing or expectorating of evaluated samples. All the panelists had previous experience in potato research and were trained specifically to recognize the musty and earthy flavour notes which were of interest in this study (see Table 1).

Sample preparation for sensory evaluation

In preliminary experiments it was found that an earthy, musty flavour, if present, occurred in raw, boiled, baked and fried potatoes. For convenience, only baking and frying of samples were chosen as routine methods of sample preparation for sensory evaluation. For baking, uniformly sized potatoes were washed and wrapped in aluminum foil with holes for excess moisture evacuation. The samples were placed in a preheated oven at 240°C and cooked for 2 h. Individual slices of approximately 30 g each were presented for sensory evaluation. For frying, potatoes were washed, peeled and cut into 1·0 × 1·0 cm strips. After slicing, the strips were rinsed in cool water, blanched in 83°C water for 3·5 min and fried in vegetable oil at 180°C for 2·5 min in a thermostatically controlled Garland deep fat fryer.

Collection and analysis of potato volatiles

Potato samples were prepared by placing 1·5 kg washed, unpeeled 1·0 cm × 1·0 cm French fry strips in a 5 litre two-neck distilling flask (Fisher Scientific Ottawa, Cat. No. 4967-56) with 2·25 litre glass distilled water pre-heated to 80 ± 2°C. Samples were cooked in a heating mantle for round-bottom flasks (Electrothermal Engineering Ltd, London) connected to a Staco Type 3PN1510 power regulator (Staco, Inc., Dayton, OH). Cooking time was 24 min with the power regulator set at 100% of maximum voltage (120 V) output and 6 min with power regulator set at 40% voltage output.

Following cooking, the potatoes were drained and cooled for about 30 min in the stoppered flask at room temperature to 60°C. Headspace volatiles of the cooled potatoes were collected and concentrated by passing a stream of purified nitrogen (80 ml/min for 15 h; 21 ± 1°C) over the samples. The nitrogen was first passed through a 30 cm 6–14 mesh activated carbon trap, and then bubbled through glass-distilled water in an all-glass impinger apparatus (Canadawide Scientific Ltd, Ottawa, Ontario). Headspace volatiles from the potato samples were adsorbed onto Tenax GC (Chromatographic Specialties Inc., Brockville, Ontario) traps prepared by packing 100 ± 2 mg of 60–80 mesh Tenax GC into a 6 mm i.d. × 12 cm Pyrex tubing between pesticide grade silanized glass wool (Supelco, Inc., Bellefonte, PA) plugs. Prior to use, Tenax GC traps were conditioned with nitrogen which was purified by passage through 8 cm long by 6 mm id traps containing freshly regenerated 5A and 13X molecular sieve. The nitrogen, at a flow rate of 30 ml/min, was then passed through the Tenax GC traps for 24 h at 185°C.

Potato volatiles were subsequently eluted from the Tenax GC traps with 1 ml of freshly redistilled ethyl ether (Fisher Scientific, Fair Lawn, NJ), and were concentrated, under a slow stream of purified nitrogen at room temperature 21 ± 2°C, to approximately 10 μl in 100 μl Pierce reacti-vials (Chromatographic Specialties Inc., Brockville, Ontario).

Concentrates of volatile compounds in ethyl ether were analyzed using a Varian Model 3400 gas chromatograph (Varian Associates, Palo Alta, CA) equipped with a flame ionization detector (FID) interfaced with a Series 600 data system for chromatography data acquisition, processing and quantitation. For simultaneous FID measurement and odour assessment of individual peaks, the column effluent was split with a zero volume tee (Chromatographic Specialties Inc., Brockville, Ontario) and routinely sniffed during gas chromatographic analyses of volatile concentrates. A 30 m × 0·25 mm i.d. fused silica capillary column packed with 1 μm J & W DB-5 [polymethyl (5% phenyl) siloxane] (J & W Scientific, Folsom, CA) was used for the separation of volatiles. The operating conditions were: injection port temperature, 230°C; detector temperature 250°C; column temperature programmed at 50°C for 5 min, 50 to 140°C and 6°C/min and from 140 to 240°C at 10°C/min; carrier gas flow rate, 1 ml He/min; linear velocity, 24 cm/s; injection volume, 1; range setting of detector attenuation, 10^{-11} amp/mV; recorder attenuation, 8 or 250 mV. Identification of the compounds was made by combined gas chromatography–mass spectrometry (GC–MS) and by comparing retention times of potato volatile compounds with those of authentic compounds run on the same column under the same conditions. A Finnigan MAT 90 mass spectrometer coupled with a Varian Model 3400 gas chromatograph was used for the GC–MS analyses. Pure compounds used in chromatography comparison were obtained from Aldrich Chemical Company, Inc. (Milwaukee, WI) and from ICN Pharmaceuticals, Inc., K & K Labs Div. (Plainview, NY). All extractions and analyses of volatiles were carried out three or more times. Data were analyzed using statistical packages available from SAS (Cary, NC).

RESULTS AND DISCUSSION

Flavour ratings are listed in Table 1 and results of the multiple comparison sensory assessments of baked and fried potatoes from seven producers are presented in Table 2. For baked samples the panel of seven judges was split into three sub-groups when assessing the magnitude of perceived flavour differences. The observed differences between the samples were considered dramatic for judge No. 7, distinctive yet still strong for judges 5 and 6 and moderate for judges 1–4. Regardless of these differences in magnitude, the direction of flavour difference and its desirability were the same in each subgroup. Observed differences between judges may be due to different personalities of panel members reflecting the so-called 'sharpeners', who try to heighten distinctions and exploit differentiation, and the 'levelers', who tend to make stimulus simpler and less differentiated if they can (Amerine *et al.*, 1965). Nevertheless, one can see that samples Nos 6 and 7 were found distinctly off-flavoured with 'earthy', 'musty' notes and significantly less desirable than samples 1 and 2, both when baked and fried. In Table 3 are

TABLE 1
Flavour Evaluation of Commercially Stored Potatoes from Eight Producers by Descriptive Analysis with Scaling

Source of potatoes	*Flavour rating* $\bar{X}$ *(cm), n = 39–59*	*Most frequent flavour description*
1 BN	3·9	good, pleasant, potato-like
2 NK	4·5	good, pleasant, potato-like
3 KR	4·4	good, pleasant, potato-like
4 HS	5·6	slightly musty, slightly earthy, strong potato-like
5 SM	6·4	floral, bitter
6 LW	9·4	very bad, earthy strong, musty strong, stale and oily
7 BL	8·3	very bad, earthy strong, musty strong, stale and oily
8 YK	4·4	good, potato-like

presented flavour difference and flavour desirability results for baked potatoes from eight additional storage facilities and producers. In all cases, potatoes which had been sprout-inhibited with the CIPC formulation containing HiSol 10 were found to possess musty, earthy, potato bin-like aroma and taste. The off-flavoured potatoes, which included samples from sources 4 HS, 6 LW, 7 BL, 11 HSP, 12 NT, 13 THS, 14 BNB, 15 BSB and 16 LWN (Tables 1–3), all possessed the distinct earthy, musty notes and were less desirable than the other samples, although not all possessed the same degree of off-flavour. Similarly, potatoes which were not sprout-inhibited (8 YK, 9 GR) and potatoes which were sprout-inhibited with maleic hydrazide (2 NK, 5 SM) or the CIPC formulation containing methanol (1 BN, 3 KR, 10 MC) were all of acceptable quality; however, they were not all of the same quality and the same degree of desirability. For instance, potatoes from source 5 SM (Tables 1 and 2) were not musty or earthy, but possessed off-flavour characteristics described as bitter and floral. This note, which was not detected in French fried samples, may have been caused by high levels of glycoalkaloids which are known to impart bitterness in potatoes containing in excess of 14 mg glycoalkaloids/100 g of potatoes (Sinden *et al.*, 1976). On the basis of sensory characteristics, samples 1 BN and 2 NK representing quality potatoes, and samples 6 LW and 7 BL which were considered off-flavoured, were used for the collection and analysis of headspace volatiles. The technique for headspace concentration on Tenax GC was selected because it gives more meaningful results than volatile analyses using distillation or solvent extraction procedures (Mazza *et al.*, 1980; Barteley & Schwede, 1987; Dirinck *et al.*, 1977; Gordon, 1987).

A typical chromatogram with odour assessments of the headspace

TABLE 2
Flavour Difference and Flavour Difference Desirability of Commercially Stored Potatoes from Seven Producers Assessed Using the Multiple Comparison Test

Source of potatoes	*Flavour difference*					*Flavour desirability*				
	Baked				*Fried*	*Baked*				*Fried*
	Judges 1–4	*Judges 5–6*	*Judge 7*	*Judges 1–7*	*Judges 1–7*	*Judges 1–4*	*Judges 5–6*	*Judge 7*	*Judges 1–7*	*Judges 1–7*
1 BN	0·7 *a*[a]	0·6 *a*	4·7 *a*	1·2 *a*	0·9 *a*	−0·3 *a*	−0·2 *a*	+0·1 *a*	−0·2 *a*	0·1 *a*
2 NK	1·7 *ab*	3·2 *ab*	3·7 *a*	2·3 *ab*	1·1 *a*	−0·3 *a*	−1·3 *ab*	+1·3 *a*	−0·3 *a*	−0·1 *a*
3 KR	2·6 *bc*	2·6 *ab*	4·9 *a*	2·9 *bc*	1·4 *a*	−1·3 *b*	−1·0 *ab*	−0·03 *a*	−1·0 *b*	−0·2 *a*
4 HS	2·4 *b*	4·4 *b*	7·7 *b*	3·7 *cd*	5·0 *b*	−1·4 *bc*	−2·1 *b*	−2·8 *b*	−1·8 *c*	−2·7 *b*
5 SM	3·9 *cd*	3·4 *b*	8·1 *b*	4·4 *de*	1·9 *a*	−2·0 *bc*	−1·3 *ab*	−3·5 *b*	−2·1 *cd*	−0·5 *a*
6 LW	3·1 *bcd*	7·5 *c*	8·5 *b*	5·1 *ef*	4·2 *b*	−1·8 *bc*	−3·7 *c*	−3·8 *b*	−2·7 *de*	−2·3 *b*
7 BL	4·5 *d*	8·6 *c*	9·0 *b*	6·2 *t*	5·5 *b*	−2·2 *c*	−4·3 *c*	−4·3 *b*	−3·1 *e*	−2·8 *b*

[a] Within each column means followed by the same letter are not significantly different ($P \leq 0{\cdot}01$) using Duncan's multiple range test.

TABLE 3
Flavour Difference and Flavour Desirability of Baked Potatoes Assessed using Multiple Comparison Test

Source of potatoes	*Flavour difference*	*Flavour desirability*
9 GR	1·4 *a*	−0·2 *a*
10 MC	1·9 *ab*	−0·3 *a*
11 HSP	3·2 *bc*	−1·0 *ab*
12 MT	3·9 *cd*	−1·7 *bc*
13 THS	4·1 *cd*	−2·0 *cd*
14 BNB	4·9 *de*	−2·3 *cd*
15 BSB	5·3 *de*	−2·7 *d*
16 LWN	5·7 *e*	−2·8 *d*

Within each column means followed by the same letter are not significantly different ($P \leq 0{\cdot}01$) using Duncan's multiple range test.

volatiles from freshly boiled Russet Burbank potatoes exhibiting a musty, earthy flavour is shown in Fig. 1. Concentrates of headspace volatiles obtained from both off-flavour and quality potatoes gave qualitatively very similar results on GC–MS analyses and on odour assessment of column effluent. The identified compounds, listed according to the order of elution on DB-5, are presented in Table 4. Identification of the peaks was accomplished on the basis of mass spectral and retention time data. Many of the compounds identified in this work have been reported in potatoes by

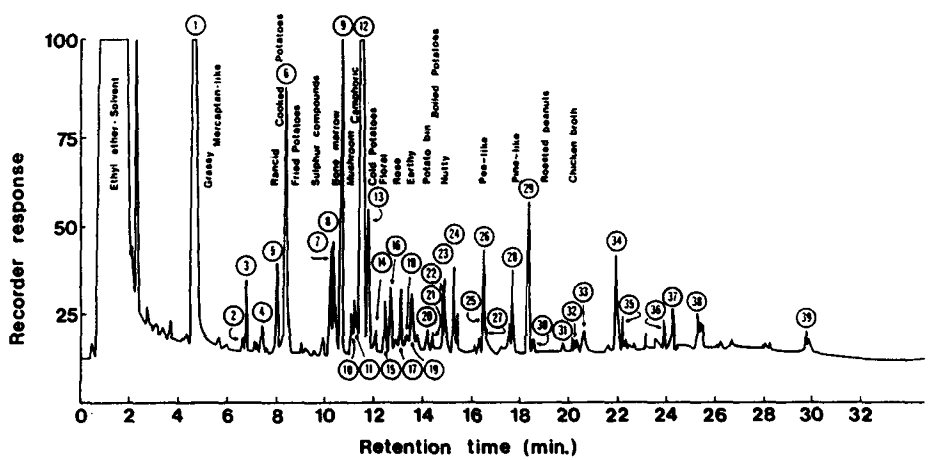

Fig. 1. Fused silica capillary column (DB-5, 30 m × 0·25 mm) separation of headspace volatiles collected from boiled potatoes. Temperature program: 50°C for 5 min, 50 to 140°C at 6°C/min and from 140 to 240°C, 10°C/min. Carrier gas: helium, 1 ml/min. Sample: 1·0 μl aliquot from 10 μl essence obtained from extraction of 1·5 kg potatoes. Odour assessment indicated. Peak numbers refer to components listed in Table 3.

TABLE 4
Volatile Aroma Compounds Identified in Headspace Concentrates of Freshly Boiled Off-Flavoured Russet Burbank Potatoes

Peak[a]	*Retention time (min)*	*Compound*		*Peak area (%)*
		Name	*Formula*	
1	4·7	hexanal	$C_6H_{12}O$	55·09
2	6·6	2-methyl-2-pentanol[b]	$C_6H_{14}O$	0·12
3	6·8	1,3-dimethylbenzene	C_8H_{10}	0·52
4	7·4	4-methyl-3-heptene[b]	C_8H_{16}	0·18
5	8·0	2,4-octadienal	$C_8H_{12}O$	0·98
6	8·4	heptanal + c4-heptenal	$C_7H_{14}O + C_7H_{12}O$	1·96
7	10·3	benzaldehyde	C_7H_6O	0·71
8	10·4	2-heptenal[b]	$C_7H_{12}O$	0·79
9	10·7	1,3,5-trimethylbenzene	C_9H_{12}	2·27
10	11·1	1-ethyl-4-methylbenzene[b]	C_9H_{12}	0·37
11	11·2	1-hepten-3-ol[b]	$C_7H_{14}O$	0·49
12	11·5	2-pentylfuran/2,4-nonadienal	$C_9H_{14}O$	15·26
13	11·8	octanal	$C_8H_{16}O$	1·29
14	12·1	1,3-dichlorobenzene	$C_6H_4Cl_2$	0·41
15	12·5	1,2,3-trimethylbenzene	C_9H_{12}	0·46
16	12·7	3-ethyl-2-methyhexadiene *or* 4-methyl-2-propylfuran[b]	C_9H_{16} *or* $C_8H_{12}O$	0·49
17	13·0	phenylacetaldehyde	C_8H_8O	0·61
18	13·3	diethylbenzene[b]	$C_{10}H_{14}$	0·26
19	13·6	2-octenal[b]	$C_8H_{14}O$	0·90
20	14·2	methyl(1-methylethyl)-benzene[b]	$C_{10}H_{14}$	0·30
21	14·4	2-methoxy-3-(1-methylethyl) pyrazine[b]	$C_8H_{12}N_2O$	0·21
22	14·8	pulegone[b]	$C_{10}H_{16}O$	0·38
23	14·9	nonanal	$C_9H_{18}O$	0·67
24	15·3	1,2,3,5-tetramethylbenzene	$C_{10}H_{14}$	0·53
25	16·3	1,2,3,4-tetramethylbenzene	$C_{10}H_{14}$	0·16
26	16·5	2,3,5,6-tetramethylphenol[b]	$C_{10}H_{14}O$	0·68
27	16·6	naphthalene[b]	$C_{10}H_8$	0·27
28	17·6	decanal	$C_{10}H_{20}O$	0·19
29	18·4	2-methoxy-1,3,5-trimethyl-benzene	$C_{10}H_{14}O$	0·96
30	18·6	2,4-dimethoxybenzoic acid[b]	$C_9H_{10}O_4$	0·15
31	19·7	pentamethylbenzene[b]	$C_{11}H_{16}$	0·15
32	20·1	trimethyldecane[b]	$C_{13}H_{28}$	0·14
33	20·6	2,4-decadienal[b]	$C_{10}H_{16}O$	0·38
34	21·9	hexanoic acid[b]	$C_6H_{12}O_3$	0·68
35	22·2	copaene[b]	$C_{15}H_{24}$	0·25
36	23·6	pentadecane[b]	$C_{15}H_{32}$	0·30
37	24·2	trimethyldodecane[b]	$C_{12}H_{32}$	0·32
38	25·4	dimethylbiphenyl-2-ol	$C_{16}H_8O$	0·60
39	29·7	diheptylpentadecane	$C_{29}H_{60}$	0·20

[a] Refers to peak number in Fig. 1. [b] Identification based on MS data only.

other investigators (Nursten & Sheen, 1974; Coleman *et al.*, 1981; Josephson & Lindsay, 1987). The major component of the headspace concentrates from off-flavour and quality potatoes was hexanal. Other prominent components included 2-pentylfuran, heptanal, octanal, phenylacetaldehyde, benzaldehyde and several aromatic hydrocarbons. None of the many known earthy, musty type compounds, such as 2-methoxy-3-isopropyl, 2-methoxy-3-ethylpyrazine, geosmin (*trans*-1, 10-dimethyl-*trans*-9-decanol), 2-methylisoborneol and 2,4,6-trichloroanisole (Buttery & Ling, 1973; Gerber, 1979) were detected by GC–MS analyses. Odour assessment of the column effluent, however, revealed that distinctly earthy, potato bin-like aromas, as well as cold potato aromas, were present in the concentrates of headspace from raw, boiled and baked potatoes. The region in the chromatogram coinciding with the earthy, potato bin-like aromas contained 4–5 compounds including 2-octenal and a 2-methoxypyrazine (*m/z* 124·1, 127·1, 137·0, 152·1), suggesting that these, as well as undetected and/or unidentified earthy, musty type compounds, may have been present in the samples. Also, injections of authentic 2-isopropyl-3-methoxypyrazine onto the GC column revealed that the retention time of this compound (Rt, 14·7) coincided with the earthy region on the chromatogram (Fig. 1).

Statistical comparisons of the peak areas and peak area/total area ratios for 97 peaks on the chromatograms of headspace concentrates from earthy, musty potatoes (6 LW and 7 BL, Tables 1–7) and quality potatoes (1 BN and 2 NK, Tables 1–7) revealed that six major components were significantly more concentrated in off-flavour than in quality potatoes (Tables 5–7). These compounds were all derivatives of benzene and three of them were identified as 1,2,3- and 1,3,5-trimethylbenzene and 1,2,3,5-tetramethylbenzene. These aromatic hydrocarbons were 2 to 10 times more concentrated in the off-flavour than in quality potatoes. The compounds were also identified as the major components of HiSol 10 which constituted approximately 7% of the sprout inhibitor formulation used to treat the musty, earthy potato samples. The other three peaks were tentatively identified as 2,3,5-6-tetramethylphenol, 2-methoxy-1,3,5-trimethylbenzene and 2,4-dimethoxybenzoic acid. All six compounds were also present, albeit at lower concentrations, in quality potatoes.

Trimethyl- and tetramethylbenzene have been reported as components of potatoes by other investigators (Nursten & Sheen, 1974; Coleman *et al.*, 1981) but their role in potato flavour has been minimized. The results of this study, however, strongly suggest that these and/or other aromatic compounds play a significant role in the occurrence of the earthy, musty off-flavour in potatoes. This off-flavour may be caused by the higher concentration of aromatic compounds in the tubers, and thus enhancement/imbalance in the flavour components or an alteration in the flavour

TABLE 5

Headspace Volatiles of Boiled Potatoes Significantly More Concentrated in Off-Flavoured Potatoes (6 LW and 7 BL) than in Quality Potatoes (2 NK and 1 BN)

Peak[a]	*Retention time (min)*	*Compound*		*Peak area/total area* ($\times 10^{-3}$) *for potato extracts*			
		Name	*Formula*	*6 LW*	*7 BL*	*2 NK*	*1 BN*
9	10·71	1,3,5-trimethylbenzene	C_9H_{12}	22·0 *a*[b]	16·0 *b*	2·0 *c*	3·0 *c*
15	12·46	1,2,3-trimethylbenzene	C_9H_{12}	4·8 *a*	4·6 *a*	2·5 *b*	3·0 *b*
24	15·29	1,2,3,5-tetramethylbenzene	$C_{10}H_{14}$	5·0 *a*	6·0 *a*	1·0 *b*	2·0 *b*
26	16·52	2,3,5,6-tetramethylphenol[c]	$C_{10}H_{14}O$	8·0 *a*	8·3 *a*	1·1 *b*	1·4 *b*
29	18·36	2-methoxy-1,3,5-trimethylbenzene	$C_{10}H_{14}O$	9·4 *a*	17·7 *a*	0·6 *b*	0·4 *b*
30	18·55	2,4-dimethoxybenzoic acid[c]	$C_9H_{10}O_4$	1·9 *b*	5·3 *a*	0·4 *c*	0·7 *c*

[a] Refers to peak number in Fig. 1.
[b] Within each row means followed by the same letter are not significantly different ($P \leq 0{\cdot}05$) using Duncan's multiple range test.
[c] Identification based on MS data only.

TABLE 6

Headspace Volatiles of Baked Potatoes Significantly More Concentrated in Off-Flavoured Potatoes (6 LW and 7 BL) than in Quality Potatoes (2 NK and 1 BN)

Peak[a]	*Retention time (min)*	*Compound*		*Peak area/total area* ($\times 10^{-3}$) *for potato extracts*			
		Name	*Formula*	*6 LW*	*7 BL*	*2 NK*	*1 BN*
9	10·71	1,3,5-trimethylbenzene	C_9H_{12}	21·0 *a*[b]	28·6 *b*	6·5 *a*	9·3 *a*
15	12·46	1,2,3-trimethylbenzene	C_9H_{12}	5·9 *a*	7·2 *a*	6·1 *a*	7·5 *a*
24	15·29	1,2,3,5-tetramethylbenzene	$C_{10}H_{14}$	8·2 *a*	10·5 *a*	4·3 *a*	6·8 *a*
26	16·52	2,3,5,6-tetramethylphenol[c]	$C_{10}H_{14}O$	17·0 *b*	21·0 *b*	0·0 *a*	0·8 *a*
29	18·36	2-methoxy-1,3,5-trimethylbenzene[c]	$C_{10}H_{14}O$	23·0 *b*	30·0 *b*	0·0 *a*	1·4 *a*
30	18·55	2,4-dimethoxybenzoic acid[c]	$C_9H_{10}O_4$	4·8 *a*	11·6 *b*	6·5 *a*	3·2 *a*

[a] Refers to peak number in Fig. 1.
[b] Within each row means followed by the same letter are not significantly different ($P \leq 0{\cdot}05$) using Duncan's multiple range test.
[c] Identification based on MS data only.

TABLE 7

Headspace Volatiles of Raw Potatoes Significantly More Concentrated in Off-Flavoured Potatoes (6 LW and 7 BL) than in Quality Potatoes (2 NK and 1 BN)

Peak[a]	*Retention time (min)*	*Compound*		*Peak area/total area* ($\times 10^{-2}$) *for potato extracts*			
		Name	*Formula*	*6 LW*	*7 BL*	*2 NK*	*1 BN*
9	10·71	1,3,5-trimethylbenzene	C_9H_{12}	19·8 *b*[b]	4·0 *a*	1·5 *a*	2·4 *a*
15	12·46	1,2,3-trimethylbenzene	C_9H_{12}	2·3 *a*	1·7 *a*	1·6 *a*	2·3 *a*
24	15·29	1,2,3,5-tetramethylbenzene	$C_{10}H_{14}$	3·1 *b*	1·3 *a*	0·9 *a*	1·1 *a*
26	16·52	2,3,5,6-tetramethylphenol[c]	$C_{10}H_{14}O$	1·8 *a*	0·7 *a*	0·6 *a*	0·2 *a*
29	18·36	2-methoxy-1,3,5-trimethylbenzene[c]	$C_{10}H_{14}O$	5·9 *a*	1·9 *a*	0·0 *b*	0·0 *b*
30	18·55	2,4-dimethoxybenzoic acid[c]	$C_9H_{10}O_4$	0·4 *b*	0·5 *b*	0·0 *a*	0·1 *a*

[a] Refers to peak number in Fig. 1.
[b] Within each row means followed by the same letter are not significantly different ($P \leq 0{\cdot}05$) using Duncan's multiple range test.
[c] Identification based on MS data only.

development, through the action of the aromatic compounds on the biosynthetic pathways of earthy, musty type compounds. Currier (1951), in a study on herbicidal properties of benzene and methyl derivatives, including 1,3,5-trimethylbenzene, found that short exposures of carrots, tomatoes and barley plants to these compounds produced darkening, loss of turgor and development of odour 'normally associated with macerated tissue'. The origin of the aromatic compounds in quality potatoes is not clear. Johnson *et al.* (1969) reviewed the occurrence of aromatic hydrocarbons in many foods and discussed their possible origin. It appears that the presence of aromatic compounds in quality potatoes could be the result of: (a) adsorption of aromatic compounds used in pesticides, sprays and fuels; (b) adsorption of hydrocarbon plant constituents from decaying plant remains; (c) the breakdown of plant carotenoids to aromatic hydrocarbons, and (d) adsorption of residual aromatic compounds from sprout inhibitor formulations used in previous year(s).

CONCLUSIONS

Sensory evaluation of commercially stored Russet Burbank potatoes revealed that samples possessing a musty, earthy off-flavour were sprout-inhibited with a commercial formulation of CIPC which contained HiSol 10 as a carrier. Gas Chromatography–mass spectrophotometry analysis of concentrates of headspace volatiles from quality and off-flavour potatoes, gave qualitatively similar results but the musty, earthy potatoes were significantly richer in six benzene derivatives seemingly deriving from HiSol 10. These findings thus suggest that aromatic compounds which can originate from a variety of sources, including sprout inhibitor formulations, may play a significant role in the development of earthy, musty off-flavour in potatoes. Further work to elucidate the mechanism is, however, required.

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