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The influence of controlled atmosphere storage on the flavor and texture profiles of display-ready pork cuts

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A total of 216 commercial pork loin sections were utilized to investigate the influences of storage atmosphere, temperature, and time on the flavor and textural properties of display-ready cuts. Storage atmosphere and temperature exerted little influence on flavor and textural properties when data were pooled over storage time and storage atmosphere or storage temperature. However, both flavor and texture deteriorated progressively ($P \leq 0.05$) as storage was extended, and storage time accounted for 94 and 91%, respectively, of the variation in texture and flavor amplitude ratings when data were pooled over storage atmosphere and storage temperature. Normal flavor character notes became less prevalent and less intense ($P \leq 0.05$), and were detected later ($P \leq 0.05$), while unusual flavor character notes became more prevalent and intense ($P \leq 0.05$), and were detected earlier ($P \leq 0.05$) as storage was extended, resulting in the flavor of samples becoming unusual, unbalanced, and unblended after 12 days of storage, when data were pooled over storage atmospheres and storage temperatures. Consequently, off-flavor development constituted the limiting factor for extension of chilled pork storage life in display-ready packs, masterpacked in controlled atmospheres. Since previous research has illustrated early off-flavor development coincided with lactics reaching maximum numbers, extension of the chilled storage life of display-ready pork is dependent upon substantially improving the hygienic quality of commercial pork products. © 1997 Canadian Institute of Food Science and Technology. Published by Elsevier Science Ltd

INTRODUCTION

Considerable interest has developed within the retail sector in merchandising retail-ready pork cuts, due to the steadily increasing labor costs for fabrication of retail cuts in stores and the relatively large capital investment in floorspace, presently devoted to cut fabrication instead of product merchandising. Consequently, centralized processing of display-ready cuts offers both efficiency and economy to the industry (Farris *et al.*, 1991). However, systems utilizing conventionally overwrapped trays can be used to distribute display-ready cuts over only relatively short distances. To achieve more widespread distribution, modified or controlled atmospheres must be utilized (Young *et al.*, 1988) since, in commercial practice, the time between packaging and display in retail-ready systems often extends to three weeks, even when cuts are distributed over relatively short distances, due to the inability to cope with unpredictable fluctuations in consumer demand (Gill and McGinnis, 1993).

Presently, three atmospheres have the potential for extending the storage life of retail-ready pork cuts. These are 100% nitrogen (N_2), 100% carbon dioxide (CO_2), and a gas mixture containing a high level of oxygen (O_2) and a lower level of CO_2 (70% O_2 and 30% CO_2). Also, it is presently believed 20 days would be sufficient time to successfully distribute and merchandise centrally processed pork cuts anywhere in the United States or Canada. Consequently, the masterpacking of display-ready cuts in carbon dioxide, nitrogen, or a mixture of oxygen, carbon dioxide, and possibly nitrogen appears to offer the most viable alternatives for chilled storage life extension to permit more widespread distribution of display-ready cuts (Gill and Jones, 1994*a*,*b*, 1996; Jeremiah, *et al.*, 1995*a*,*b*, 1996).

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Therefore, although both modified and controlled atmospheres have been proposed as potential techniques for extending the storage life of centrally processed, display-ready pork cuts, very little knowledge is available from the literature regarding the use of different atmospheres for extension of chilled storage life under varying storage conditions, particularly with display-ready packages of pork, and the influence of these storage parameters on the eating quality of the product. Consequently, the present research was designed to assess the storage life of retail-ready pork cuts following storage in controlled atmospheres of the three previously mentioned gases and gas mixture during storage for 4-day intervals up to 28 days, under optimum (−1.5%), commercial (2°C), and potentially abusive (5°C) storage temperatures, with a subsequent 30-h, aerobic, display period.

EXPERIMENTAL

A total of 216 loin samples from 54 commercial, boneless pork loins with normal inherent muscle quality obtained from a local, federally inspected pork processing plant were utilized. All loins were cut into four equal-sized subsections, and the subsections were randomly allocated to storage atmosphere, storage temperature, and storage interval subgroups.

Packaging and storage

All subsections were placed on a soaker pad in a hard plastic tray and then were overwrapped with an oxygen permeable film (Vitafilm 'Choice Wrap', Huntsman Corp., Toronto, ON). Two vent holes were then burned through the overwrap film (one at each end of the package) to permit free exchange of atmospheres within the masterpack. The retail-ready packs were then placed into foil-laminate pouches, evacuated, filled with an excess of the designated atmosphere, and heat-sealed, prior to being placed into storage at the designated temperature. Following storage for the designated interval, cuts were displayed under simulated retail conditions (in a Hussmann horizontal-type retail display case (model: M1-12, Hill Refrigeration of Canada Ltd, Barrie, ON), under 1076 lux of incandescent and fluorescent lighting for 12 h per day (mean temperature at the meat surface was 6.8°C), for 30 h).

Sample preparation and evaluation

Unless samples had been determined to be spoiled on the basis of appearance and/or odor, they were vacuum-packaged, frozen at −30°C in still air, and stored at this temperature 90 to 120 days prior to flavor and texture profile analysis according to the procedure previously outlined (Jeremiah *et al.*, 1992*a*).

A thermocouple was inserted into the center of each loin subsection. The loin subsections were then placed into a preheated electric convection oven at 177°C and roasted to an internal temperature of 75°C. Upon removal from the oven, each loin subsection was cut into cubes (1.9 × 1.9 × 1.9 cm) taking care to avoid large pieces of fat and connective tissue. A total of seven cubes from each loin was then randomly assigned to each panel member and placed into covered glass containers in a circulating water bath (50°C). All containers remained in the water bath for 10–15 min until the samples were evaluated.

Sample assessments were made in well-ventilated, temperature-controlled, partitioned booths under 1076 lux of incandescent and fluorescent lighting. Distilled water (room temperature) and unsalted soda crackers were provided for removal of residual flavors between each sample evaluation (Larmond, 1977).

All samples were evaluated by a highly trained flavor-texture profile panel, screened and trained according to the procedures of Meilgaard *et al.* (1987), Munoz and Civille (1992), and Jeremiah *et al.* (1988*a*,*b*). A pool of twelve trained panelists was utilized and no fewer than six of these panelists were present at any panel session. Two loin subsections chosen at random were evaluated at each panel session. Initially, panelists formulated profiles for each sample individually and, after the individual assessments were made, consensus profiles were developed through group discussion (Jeremiah *et al.*, 1988*a*,*b*). During this process, consensus (a unanimous decision) was reached on the character notes making up the profile, as well as on order of appearance, intensity, and amplitude ratings. All data analyses were performed using consensus data, and flavor and texture profile data were analyzed by methods previously described (Jeremiah, 1988; Jeremiah *et al.*, 1988*a*,*b*, 1990, 1991).

All perceived flavor sensations (character notes, Appendix A) including aroma notes, were described, and textural properties (character notes) were described and evaluated as previously described (Jeremiah, 1988; Jeremiah *et al.*, 1988*a*). The order of appearance of each flavor character note was ranked on all samples (1 = appearing first; 2 = appearing second, etc.). Flavor notes were also identified as aromatics, tastes, mouth-feelings, and aftertastes or afterfeelings. Textural character notes were evaluated in stages (stage 1 = surface properties; stage 2 = partial compression properties; stage 3 = first bite properties; stage 4 = mastication properties; and stage 5 = afterfeeling properties). The intensities of flavor character notes and certain texture character notes were scaled using magnitude estimation with a fixed modulus (0–15 with reference standards) (Civille, 1982; Jeremiah, 1988; Jeremiah *et al.*, 1988*a*,*b*, 1990, 1991). Ratings of amplitude or overall impression (normality of individual character notes for roast pork loin and how well blended and balanced they were) were also obtained. Thus, complete flavor and texture profiles were obtained for each sample.

Data from the flavor profile panel, denoting differences in the percentages of samples displaying certain flavor properties, and data from the texture profile panel, denoting differences in the percentages of samples displaying certain textural properties, were tested for significance using the χ-square test. Data from the flavor profile panel, encompassing intensity, order of appearance, and amplitude ratings, and data from the texture profile panel, encompassing intensity and amplitude ratings, were analyzed using a three-factorial design, with storage atmosphere, temperature, and time as the main effects, with four samples per subgroup, and the GLM procedure of SAS (SAS, 1989) which gives an analysis of variance with a comparison of least-square means using the Student's *t*-test. Linear regression was utilized to detect significant ($P \leq 0.05$) time trends with duration of chilled storage and subsequent aerobic display, and increasing storage temperature (Puri and Mullen, 1980). Meaningful storage atmosphere/storage temperature/storage time interactions were not detected. These main effects are, therefore, discussed separately.

RESULTS

Textural properties

Effects of storage atmosphere

Samples stored in 70% oxygen and 30% carbon dioxide had a smoother surface than samples stored in 100% carbon dioxide, and released more fat during the first bite and mastication than samples stored in 100% carbon dioxide and 100% nitrogen ($P \leq 0.05$) (Table 1). However, samples stored in 100% carbon dioxide had a higher proportion of connective tissue described as webbed fibers and soft gristle than samples stored in 100% nitrogen ($P \leq 0.05$). They also produced higher proportions of residual particles described as grainy, mealy, mushy, crumbly, and spongy, and grainy, mealy, crumbly, stringy, and spongy, than samples stored in 70% oxygen and 30% carbon dioxide and 100% nitrogen. In addition, they produced higher proportions of residual particles described as grainy, mealy, mushy, crumbly, stringy, and spongy than samples stored in 100% nitrogen. Samples stored in 100% nitrogen produced higher proportions of residual particles described as grainy, mealy, mushy, crumbly, and stringy, and grainy, mealy, crumbly, mushy, sticky, stringy, and gristle than samples stored in 100% carbon dioxide and 70% oxygen and 30% carbon dioxide. Samples stored in 70% oxygen and 30% carbon dioxide produced higher proportions of residual particles described as grainy, mealy, crumbly, and stringy than samples stored in 100% nitrogen and 100% carbon dioxide. Moreover, they resulted in less toothpicking than samples stored in 100% nitrogen and 100% carbon dioxide. However, these differences were not of sufficient magnitude to influence texture amplitude or the normality, balance, and blendedness of the combined texture character notes.

Effects of storage temperature

Samples stored at −1.5°C had fewer surface particles and were less elastic during partial compression than samples stored at 2 and 5°C ($P \leq 0.05$) (Table 2). They also produced a higher proportion of residual particles described as grainy, mealy, mushy, crumbly, and stringy ($P \leq 0.05$) than samples stored at 2 and 5°C. These differences, however, were not of sufficient magnitude to influence texture amplitude or the normality, balance, and blendedness of the combined texture character notes ($P \leq 0.05$). Significant negative trends with increasing storage temperature were observed in uniformity ($P \leq 0.01$, $R^2 = 0.96$) and density ($P \leq 0.05$, $R^2 = 0.84$) of samples during mastication and the ease with which samples were swallowed ($P \leq 0.05$, $R^2 = 0.8$), indicating that as storage temperature increased, samples became less dense and uniform and more difficult to swallow. In addition, significant positive trends with increasing storage temperature were detected in the amount of residual particles ($P \leq 0.05$, $R^2 = 0.84$) and the proportion of residual particles described as grainy, mealy, mushy, crumbly, stringy, and spongy ($P \leq 0.01$, $R^2 = 0.88$), indicating both the amount of residual particles and the proportion of this unusual residual particle type increased with storage temperature.

Effects of storage time

Although statistically significant differences ($P \leq 0.05$) were observed in most texture character notes, they were generally not consistent (Table 3). However, significant positive time trends in elasticity during partial compression ($P \leq 0.05$, $R^2 = 0.51$), the proportions of fibers described as medium and medium plus ($P \leq 0.05$, $R^2 = 0.66$ and 0.64 respectively), cohesiveness ($P \leq 0.05$, $R^2 = 0.79$) and the amount of connective tissue during mastication ($P \leq 0.03$, $R^2 = 0.64$), and the proportion of residual particles described as grainy, mealy, crumbly, stringy, and spongy ($P \leq 0.05$, $R^2 = 0.74$) were observed with the extension of storage time. Moreover, significant negative time trends in the ease of swallowing ($P \leq 0.01$, $R^2 = 0.80$) and residual fat amount ($P \leq 0.05$, $R^2 = 0.55$) were observed as storage time was prolonged. These trends combined to produce a significant negative time trend in texture amplitude or the normality, balance, and blendedness of combined texture character notes ($P \leq 0.01$, $R^2 = 0.94$), indicating texture deteriorated progressively as storage time was extended and storage time accounted for 94% of the variation in texture amplitude ratings, when the data were pooled over storage atmospheres and storage temperatures.

Table 1. Texture profiles of samples stored in different atmospheres*

Character note		Pack atmosphere		
		100% CO_2	70% O_2, 30% CO_2	100% N_2
Surface properties				
Smoothness		8.79[b]	9.02[a]	8.95[ab]
Surface moisture		2.88	2.99	2.87
Fat amount		0.37	0.42	0.33
Fat type[1]:	A (%)	100.0	100.0	100.0
Amount of particles		1.44	1.39	1.47
Partial compression properties:				
Elasticity		5.84	5.75	5.90
First bite properties				
Compressibility		6.79	6.81	6.91
Moisture release		3.29	3.29	3.10
Fat amount		0.49[b]	0.61[a]	0.44[b]
Fat type[1]:	A (%)	100.0	100.0	100.0
Cohesiveness		7.36	7.32	7.42
Mastication properties				
Number of chews		31.4	31.3	32.0
Chewiness		8.55	8.60	8.70
Rate of breakdown		8.36	8.42	8.34
Fibrousness		7.22	7.18	7.27
Fiber type[2]:	A (%)	17.1	26.1	25.4
	B (%)	36.6	42.0	34.9
	C (%)	41.5	29.0	34.9
	D (%)	3.7	2.9	4.8
	E (%)	1.2	0.0	0.0
Moisture release		3.13	3.14	3.00
Moisture absorption		6.59	6.58	6.56
Cohesiveness		7.36	7.32	7.42
Fat amount		0.52[b]	0.62[a]	0.43[b]
Fat type[1]:	A (%)	100.0	100.0	100.0
Uniformity		11.70	11.76	11.82
Density		8.96	8.95	9.08
Connective tissue amount		7.39	7.36	7.49
Connective tissue type[2]:	A (%)	79.3	95.7	95.2
	B (%)	3.7	0.0	1.6
	C (%)	17.1[a]	4.3[ab]	1.6[b]
	D (%)	0.0	0.0	1.6
Afterfeeling properties:				
Ease of swallowing		9.05	9.04	8.95
Fat amount		0.48	0.52	0.41
Fat type[1]:	A (%)	100.0	100.0	100.0
Mouthcoating amount		3.27	3.26	3.17
Mouthcoating type[4]:	A (%)	19.5	21.7	14.3
	B (%)	80.5	78.3	85.7
Particle amount		2.85	2.81	2.83
Particle type[5]:	A (%)	9.8[a]	2.9[ab]	0.0[b]
	B (%)	19.5[b]	23.2[b]	39.7[a]
	C (%)	4.9	0.0[b]	0.0[b]
	D (%)	6.1	2.9	4.8
	E (%)	9.8[a]	1.4[b]	0.0[b]
	F (%)	18.3[b]	33.3[a]	17.5[b]
	G (%)	0.0	1.4	0.0
	H (%)	1.2	0.0	0.0
	I (%)	1.2	0.0	0.0
	J (%)	7.3	8.7	7.9
	K (%)	2.4	1.4	0.0
	L (%)	1.2	4.3	6.3
	M (%)	3.7	1.4	0.0
	N (%)	9.8[b]	13.0[b]	39.7[a]
	O (%)	0.0	0.0	1.6
	P (%)	3.7	1.4	3.2
	Q (%)	1.2	4.3	1.6
Toothpacking		2.32[a]	2.22[b]	2.34[a]
Amplitude		8.88	8.90	8.94

*Generated by 6 to 12 highly trained profile panelists.
[a,b,c]Means in the same row without a superscript or bearing a common superscript do not differ significantly ($P \geq 0.02$).
[1]Fat type: A = Greasy
[2]Fiber type: A = Fine; B = Fine +; C = Medium; D = Medium +; E = Coarse.
[3]Connective tissue type: A = Webbed fibers; B = Webbed fibers and hard gristle; C = Webbed fibers and soft gristle; D = Webbed fibers and soft and hard gristle.
[4]Mouthcoating type: A = Particles; B = Particles and greese.
[5]Particle type: A = Grainy, mealy, mushy, crumbly, stringly, and spongy; B = Grainy, mealy, mushy, crumbly and stringy; C = Grainy, mealy, mushy, crumbly, and spongy; D = Grainy, mealy, mushy, and crumbly; E = Grainy, mealy, crumbly, stringy, and spongy; F = Grainy, mealy, crumbly, and stringy; G = Grainy, mealy, crumbly, and spongy; H = Grainy, mushy, crumbly, and stringy; I = Mushy, crumbly, spongy, gummy, and stringy; J = Grainy, mealy, crumbly, stringy, sticky, and gristle; K = Grainy, mealy, crumbly, stringy, sticky, spongy and gristle; L = Grainy, mealy, crumbly, mushy, sticky, and gristle; M = Grainy, mealy, crumbly, mushy, sticky, spongy, and gristle; N = Grainy, mealy, crumbly, mushy, sticky, stringy, and gristle; O = Grainy, mealy, stringy, and spongy; P = Grainy, mealy, crumbly, mushy, sticky, stringy, spongy, and gristle; Q = Grainy, mealy, crumbly, sticky, and gristle.

Table 2. Texture profiles of samples stored at different temperatures*

Character note		Storage temperature (°C)		
		−1.5	2.0	5.0
Surface properties				
Smoothness		9.00	8.91	8.86
Surface moisture		2.98	2.84	2.92
Fat amount		0.42	0.37	0.34
Fat type[1]:	A (%)	100.0	100.0	100.0
Amount of particles		1.31^{b}	1.51^{a}	1.48^{a}
Particle compression properties				
Elasticity		5.70^{b}	5.89^{a}	5.89^{a}
First bite properties				
Compressibility		6.79	6.92	6.81
Moisture release		3.29	3.17	3.23
Fat amount		0.56	0.50	0.48
Fat type[1]:	A (%)	100.0	100.0	100.0
Cohesiveness		7.35	7.43	7.31
Mastication properties:				
Number of chewes		31.4	32.1	31.2
Chewiness		8.56	8.68	8.60
Rate of breakdown		8.44	8.33	8.36
Fibrousness		7.16	7.30	7.20
Fiber type[2]:	A (%)	20.8	18.6	28.4
	B (%)	40.3	44.3	28.4
	C (%)	32.5	32.9	41.8
	D (%)	6.5	2.9	1.5
	E (%)	0.0	1.4	0.0
Moisture release		3.16	3.04	3.07
Moisture absorption		6.57	6.58	6.61
Cohesiveness		7.56	7.56	7.47
Fat amount		0.57	0.47	0.53
Fat type[1]:	A (%)	100.0	100.0	100.0
Uniformity		11.78	11.77	11.73‡
Density		9.04	9.00	8.94†
Connective tissue amount		7.37	7.45	7.41
Connective tissue type[3]:	A (%)	93.5	87.1	86.6
	B (%)	1.3	2.9	1.5
	C (%)	5.2	10.0	10.4
	D (%)	0.0	0.0	1.5
Afterfeeling properties:				
Ease of swallowing		9.09	9.02	8.93†
Fat amount		0.50	0.44	0.46
Fat type[1]:	A (%)	100.0	100.0	100.0
Mouthcoating amount		3.25	3.20	3.25
Mouthcoating type[4]:	A (%)	14.3	22.9	19.4
	B (%)	85.7	77.1	80.6
Particle amount		2.81	2.83	2.86†
Particle type[5]:	A (%)	2.6	4.3	7.5‡
	B (%)	36.4^{a}	25.7^{ab}	16.4^{b}
	C (%)	2.6	0.0	3.0
	D (%)	3.9	2.9	7.5
	E (%)	1.3	5.7	6.0
	F (%)	22.1	27.1	19.4
	G (%)	0.0	0.0	1.5
	H (%)	0.0	1.4	0.0
	I (%)	0.0	0.0	1.5
	J (%)	5.2	10.0	9.0
	K (%)	1.3	2.9	0.0
	L (%)	3.9	5.7	1.5
	M (%)	1.3	2.9	1.5
	N (%)	14.3	10.0	14.9
	O (%)	0.0	0.0	1.5
	P (%)	1.3	0.0	0.0
	Q (%)	3.9	1.4	1.5
Toothpacking		2.25	2.32	2.30
Amplitude		9.00	8.85	8.86

*Generated by 6 to 12 highly trained profile panelists.
[a,b,c]Means in the same row without a superscript or bearing a common superscript do not differ significantly ($P \geq 0.05$)
[1]Fat type: A = Greasy
[2]Fiber type: A = Fine; B = Fine + ; C = Medium; D = Medium + ; E = Coarse.
[3]Connective tissue type: A = Webbed fibers; B = Webbed fibers and hard gristle; C = Webbed fibers and soft gristle; D = Webbed fibers and soft and hard gristle.
[4]Mouthcoating type; A = Particles; B = Particles and grease.
[5]Particle type: A = Grainy, mealy, mushy, crumbly, stringy, and spongy; B = Grainy, mealy, mushy, crumbly and stringy; C = Grainy, mealy, mushy, crumbly, and spongy; D = Grainy, mealy, mushy, and crumbly; E = Grainy, mealy, crumbly, stringy, and spongy; F = Grainy, mealy, crumbly, and stringy; G-Grainy, mealy, crumbly, and spongy; H = Grainy, mushy, crumbly, and stringy; I = Mushy, crumbly, spongy, gummy, and stringy; J = Grainy, mealy, crumbly, stringy, sticky, and gristle; K = Grainy, mealy, crumbly, stringy, sticky, spongy and gristle; L = Grainy, mealy, crumbly, mushy, sticky, and gristle; M = Grainy, mealy, crumbly, mushy, sticky, spongy, and gristle, N = Grainy, mealy, crumbly, mushy, sticky, stringy, and gristle; O = Grainy, mealy, stringy, and spongy; P = Grainy, mealy, crumbly, mushy, sticky, stringy, spongy, and gristle; Q = Grainy, mealy, crumbly, sticky, and gristle.
† $P < 0.05$ temperature trend.
‡ $P < 0.01$ temperature trend.

Table 3. Texture profiles of samples stored for different intervals*

Character Note		Storage interval (days)						
		0	4	8	12	16	20	24
Surface properties								
Smoothness		9.15^{a}	8.96^{ab}	9.00^{ab}	8.81^{b}	8.82^{b}	9.13^{a}	8.56^{c}
Surface moisture		3.17^{a}	3.02^{ab}	2.76^{bc}	2.98^{ab}	2.64^{c}	2.94^{ab}	2.89^{abc}
Fat amount		0.55^{a}	0.45^{ab}	0.30^{c}	0.38^{bc}	0.28^{c}	0.29^{c}	0.38^{abc}
Fat type[1]:	A(%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Amount of particles		1.27	1.41	1.45	1.49	1.43	1.33	1.66
Partial compression properties								
Elasticity		5.67^{b}	5.74^{b}	5.78^{b}	5.70^{b}	5.82^{b}	6.21^{a}	$5.91^{abc\dagger}$
First bite properties:								
Compressibility		6.70^{b}	6.77^{b}	6.74^{b}	6.69^{b}	6.85^{b}	7.22^{a}	6.90^{ab}
Moisture release		3.36	3.35	3.12	3.25	2.99	3.31	3.22
Fat amount		0.70^{a}	0.65^{ab}	0.38^{d}	0.57^{abc}	0.43^{cd}	0.40^{d}	0.48^{bcd}
Fat type[1]:	A (%)	100.00	100.0	100.0	100.0	100.0	100.0	100.0
Cohesiveness		7.23	7.33	7.31	7.23	7.33	7.57	7.56
Mastication properties:								
Number of chews		31.0	31.0	31.1	30.7	32.2	33.1	31.6
Chewiness		8.39	8.51	8.49	8.50	8.75	8.87	8.79
Rate of breakdown		8.58	8.53	8.50	8.28	8.23	8.14	8.34
Fibrousness		7.13	7.13	7.18	7.11	7.23	7.46	7.31
Fiber type[2]:	A (%)	30.6^{a}	25.0^{a}	22.2^{a}	25.0^{a}	18.1^{a}	5.3^{b}	22.2^{a}
	B (%)	33.3^{a}	44.4^{a}	41.7^{a}	38.9^{a}	42.4^{a}	36.8^{a}	16.7^{b}
	C (%)	33.3^{b}	30.6^{b}	33.3^{b}	33.3^{b}	30.3^{b}	47.4^{ab}	$55.6^{a\dagger}$
	D (%)	2.8^{bc}	0.0^{c}	2.8^{bc}	2.8^{bc}	6.1^{ab}	10.5^{a}	$5.6^{ab\dagger}$
	E (%)	0.0	0.0	0.0	0.0	3.0	0.0	0.0
Moisture release		3.36^{a}	3.24^{ab}	3.00^{bc}	3.10^{b}	2.82^{c}	3.00^{bc}	3.11^{abc}
Moisture absorption		6.28^{c}	6.39^{c}	6.56^{bc}	6.50^{bc}	6.99^{a}	6.77^{ab}	6.62^{abc}
Cohesiveness		7.34^{c}	7.45^{bc}	7.50^{ab}	7.39^{c}	7.60^{a}	7.73^{ab}	$7.71^{ab\ddagger}$
Fat amount		0.75^{a}	0.72^{a}	0.40^{c}	0.56^{b}	0.38^{c}	0.35^{c}	0.51^{bc}
Fat type[1]:	A (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Uniformity		11.86^{a}	11.92^{a}	11.87^{a}	11.60^{bc}	11.77^{ab}	11.80^{ab}	11.50^{c}
Density		8.97	9.14	8.87	8.92	9.04	9.17	8.86
Connective tissue amount		7.32	7.35	7.38	7.26	7.40	7.58	$7.58^{\dagger}$
Connective tissue type[3]:	A (%)	88.9^{a}	83.3^{ab}	94.4^{a}	94.4^{a}	97.0^{a}	94.7^{a}	61.1^{b}
	B (%)	0.0^{b}	5.6^{a}	0.0^{b}	0.0^{b}	0.0^{b}	5.3^{a}	5.6^{a}
	C (%)	8.3^{bc}	11.1^{b}	5.6^{bc}	5.6^{bc}	3.0^{cd}	0.0^{d}	33.3^{a}
	D (%)	2.8	0.0	0.0	0.0	0.0	0.0	0.0
Afterfeeling properties								
Ease of swallowing		9.49^{a}	9.28^{ab}	9.01^{bc}	8.73^{bc}	8.89^{d}	8.61^{cd}	$8.61^{d\ddagger}$
Fat amount		0.70	0.62^{a}	0.38^{bc}	0.49^{b}	0.31^{c}	0.41^{bc}	$0.37^{bc\dagger}$
Fat type[1]:	A (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Mouthcoating amount		3.34	3.26	3.16	3.23	3.19	3.10	3.25
Mouthcoating type[4]:	A (%)	11.1	19.4	16.7	11.1	27.3	26.3	27.8
	B (%)	88.9	80.6	83.3	88.9	72.7	73.7	72.2
Particle amount		2.72^{bc}	2.70^{c}	2.89^{ab}	2.80^{ab}	2.96^{a}	2.78^{ab}	2.96^{a}
Particle type[5]:	A (%)	0.0^{c}	0.0^{c}	2.8^{bc}	5.6^{ab}	9.1^{a}	10.5^{a}	5.6^{ab}
	B (%)	30.6^{ab}	30.6^{ab}	13.9^{cd}	25.0^{bc}	42.4^{a}	31.8^{ab}	5.6^{d}
	C (%)	2.8^{ab}	0.0^{b}	0.0^{b}	0.0^{b}	3.0^{ab}	5.3^{a}	5.6^{a}
	D (%)	5.6^{ab}	2.8^{bc}	2.8^{b}	11.1^{a}	6.1^{ab}	0.0^{c}	0.0^{c}
	E (%)	0.0^{c}	0.0^{c}	2.8^{bc}	8.3^{ab}	6.1^{ab}	5.3^{ab}	$11.1^{a\dagger}$
	F (%)	27.8^{ab}	30.6^{a}	22.2^{a}	13.9^{c}	18.2^{abc}	31.6^{a}	16.7^{bc}
	G (%)	0.0	0.0	0.0	0.0	3.0	0.0	0.0
	H (%)	0.0^{b}	0.0^{b}	0.0^{b}	0.0^{b}	0.0^{b}	0.0^{b}	5.6^{a}
	I (%)	0.0^{b}	0.0^{b}	0.0^{b}	0.0	0.0^{b}	0.0^{b}	5.6^{a}
	J (%)	8.3^{b}	5.6^{b}	22.2^{a}	8.3^{b}	0.0^{c}	0.0^{c}	5.6^{b}
	K (%)	0.0^{b}	2.8^{ab}	0.0^{b}	2.8^{ab}	0.0^{b}	0.0^{b}	5.6^{a}
	L (%)	8.3^{a}	2.8^{ab}	5.6^{a}	2.8^{ab}	0.0^{b}	0.0^{b}	5.6^{a}
	M (%)	0.0^{b}	0.0^{b}	8.3^{a}	0.0^{b}	0.0^{b}	0.0^{b}	5.6^{a}
	N (%)	5.6^{b}	19.4^{a}	16.7^{a}	16.7^{a}	9.1^{ab}	5.3^{b}	16.7^{a}
	O (%)	0.0	2.8	0.0	0.0	0.0	0.0	0.0
	P (%)	8.3^{a}	0.0^{b}	0.0^{b}	2.8^{ab}	3.0^{ab}	0.0^{b}	5.6^{a}
	Q (%)	2.8^{ab}	2.8^{ab}	2.8^{ab}	2.8^{ab}	0.0^{b}	5.3^{a}	0.0^{b}
Toothpacking		2.19^{b}	2.30^{ab}	2.21^{b}	2.31^{ab}	2.42^{a}	2.29^{ab}	2.32^{ab}
Amplitude		9.49^{a}	9.42^{a}	9.00^{b}	8.98^{bc}	8.59^{cd}	8.63^{cd}	$8.26^{d\ddagger}$

*Generated by 6 to 12 highly trained profile panelists.
[a,b,c]Means in the same row without a superscript or bearing a common supersript fo not differ significantly ($P \geq 0.05$).
[1]Fat type: A = Greasy
[2]Fiber type: A = Fine; B = Fine +; C = Medium; D = Medium +; E = Coarse
[3]Connective tissue type: A = Webbed fibers; B = Webbed fibers and hard gristle; C = Webbed fibers and soft gristle; D = Webbed fibers and soft and hard gristle.
[4]Mouthcoating type: A = Particles; B = Particles and grease
[5]Particle type: A = Grainy, mealy, mushy, crumbly, stringy, and spongy; B = Grainy, mealy, mushy, crumbly and stringy; C = Grainy, mealy, mushy, crumbly, and spongy; D = Grainy, mealy, mushy, and crumbly; E = Grainy, mealy, crumbly, stringy, and spongy; F = Grainy, mealy, crumbly, and stringy; G = Grainy, mealy, crumbly, and spongy; H = Grainy, mushy, crumbly, and stringy; I = Mushy, crumbly, spongy, gummy, and stringy; J = Grainy, mealy, crumbly, stringy, sticky, and gristle; K = Grainy, mealy, crumbly, stringy, sticky, spongy and gristle; L = Grainy, mealy, crumbly, mushy, sticky, and gristle; M = Grainy, mealy, crumbly, mushy, sticky, spongy, and gristle; N = Grainy, mealy, crumbly, mushy, sticky, stringy, and gristle; O = Grainy, mealy, stringy, and spongy; P = Grainy, mealy, crumbly, mushy, sticky, stringy, spongy, and gristle; Q = Grainy, mealy, crumbly, sticky, and gristle.
† $P < 0.05$ time trend.
‡ $P < 0.01$ time trend.

Flavor properties

Effects of storage atmosphere
Samples stored in 100% nitrogen exhibited higher incidences of the unusual unidentifiable 'off' and singed aromatics than samples stored in 100% carbon dioxide ($P \leq 0.05$) (Table 4) and a higher incidence ($P \leq 0.05$) of an unusual sour aftertaste than samples stored in 70% oxygen and 30% carbon dioxide. Samples stored in 70% oxygen and 30% carbon dioxide, however, displayed higher incidences of an unusual barnyard/urine aromatic and aftertaste than samples stored in 100% nitrogen ($P \leq 0.05$). They also displayed a higher incidence of an unusual barnyard/urine aromatic than samples stored in 100% carbon dioxide. However, samples stored in 100% nitrogen and 100% carbon dioxide exhibited a higher incidence ($P \leq 0.05$) of an unusual barnyard aromatic than samples stored in 70% oxygen and 30% carbon dioxide. Samples stored in 100% carbon dioxide exhibited a higher incidence of an unusual, unidentifiable 'off' aftertaste than samples stored in 100% nitrogen ($P \leq 0.05$). In addition, the sour taste was perceived more quickly in samples stored in 100% carbon dioxide ($P \leq 0.05$) than in samples stored in 100% nitrogen and 70% oxygen and 30% carbon dioxide. The normal fatty aromatic was more intense ($P \leq 0.05$) in samples stored in 100% carbon dioxide and 70% oxygen and 30% carbon dioxide than in samples stored in 100% nitrogen; and the normal fatty aftertaste was more intense ($P \leq 0.05$) in samples stored in 70% oxygen and 30% carbon dioxide than in samples stored in 100% nitrogen. However, the unusual livery aromatic and aftertaste and barnyard/urine aftertaste were more intense in samples stored in 70% oxygen and 30% carbon dioxide than in samples stored in 100% nitrogen and 100% carbon dioxide. The unusual barnyard aromatic, however, was more intense in samples stored in 100% nitrogen than in samples stored in 70% oxygen and 30% carbon dioxide, and the unusual barnyard aftertaste was more intense ($P \leq 0.05$) in samples stored in 100% nitrogen than in samples stored in 100% carbon dioxide and 70% oxygen and 30% carbon dioxide. These differences, however, were not of sufficient magnitude to influence flavor amplitude or the normality, balance, and blendedness of the combined flavor character notes.

Effects of storage temperature
A significant negative trend with increasing storage temperature was observed in the incidence of the normal browned aromatic ($P \leq 0.01$, $R^2 = 0.98$) indicating this desirable trait became less prevalent as storage temperature increased (Table 5). Significant positive trends were observed with increasing storage temperature in the incidence of the normal browned aftertaste ($P \leq 0.01$, $R^2 = 0.97$) and unusual livery ($P \leq 0.01$, $R^2 = 0.98$) and metallic ($P \leq 0.01$, $R^2 = 0.99$) aromatics and livery ($P \leq 0.01$, $R^2 = 0.97$) and chemical sour ($P \leq 0.05$, $R^2 = 0.95$) aftertastes. Samples stored at -1.5°C and 2°C exhibited a higher incidence of an unusual singed aromatic ($P \leq 0.05$) than samples stored at 5°C, and samples stored at -1.5 and 5°C displayed a higher incidence of an unusual chemical/barnyard/sour aftertaste than samples stored at 2°C ($P \leq 0.05$). In addition, samples stored at -1.5°C exhibited a higher incidence of an unusual chemical bite aftertaste ($P \leq 0.05$) than samples stored at 5°C. The normal browned aromatic was more intense ($P \leq 0.05$) in samples stored at 5°C than in samples stored at 2°C and was perceived more quickly ($P \leq 0.05$) from samples stored at 5°C than from samples stored at -1.5 and 2°C. However, these differences were not of sufficient magnitude to influence flavor amplitude or the normality, balance, and blendedness of the combined flavor character notes.

Effects of storage time
Significant negative time trends were observed in the incidence of the normal browned aromatic and aftertaste ($P \leq 0.01$, $R^2 = 0.79$ and 0.76, respectively) and fatty aromatic and aftertaste ($P \leq 0.05$, $R^2 = 0.64$ and 0.68, respectively), and the unusual, unidentifiable 'off' aromatic and aftertaste ($P \leq 0.01$, $R^2 = 0.69$ and $P \leq 0.05$, $R^2 = 0.52$, respectively) and chemical sour aftertaste ($P \leq 0.01$, $R^2 = 0.92$), as storage was extended, indicating these character notes became less prevalent as storage was prolonged (Table 6). Significant positive time trends were detected in the incidence of the unusual metallic aromatic and aftertaste ($P \leq 0.01$, $R^2 = 0.96$ and 0.92, respectively), barnyard/urine aromatic and aftertaste ($P \leq 0.01$, $R^2 = 0.71$ and 0.93, respectively), and singed aftertaste ($P \leq 0.05$, $R^2 = 0.68$) as storage time was extended, indicating these unusual character notes increased progressively in prevalence as storage was prolonged. In addition, significant positive time trends in the order of appearance of temperature ($P \leq 0.05$, $R^2 = 0.68$), the appropriate porky and fatty aromatics ($P \leq 0.01$, $R^2 = 0.89$ and 0.80, respectively) and sweet and salty tastes ($P \leq 0.05$, $R^2 = 0.58$ and 0.58, respectively), and the inappropriate livery aromatic ($P \leq 0.05$, $R^2 = 0.58$) and bitter taste ($P \leq 0.01$, $R^2 = 0.66$) were observed with prolonged storage, indicating these traits were perceived later as storage was extended. Significant negative time trends with prolonged storage were detected in the intensity of the normal porky, browned, and fatty aromatics ($P \leq 0.01$, $R^2 = 0.83$; $P \leq 0.01$, $R^2 = 0.70$ and $P \leq 0.05$, $R^2 = 0.54$, respectively), sweet and salty tastes ($P \leq 0.01$, $R^2 = 0.91$ and 0.89, respectively), and porky, sweet, salty, and browned aftertastes ($P \leq 0.01$, $R^2 = 0.77$, 0.74, 0.74, and 0.74, respectively), indicating these normal and desirable traits decreased progressively in intensity as storage time increased. Significant positive time trends with prolonged storage were also observed in the intensity of the unusual metallic, sour/barnyard, and barnyard/urine aromatics ($P \leq 0.01$, $R^2 = 0.74$; $P \leq 0.05$, $R^2 = 0.64$; and $P \leq 0.01$,

Table 4. Flavor profiles of samples stored in different atmospheres*

Character note	Incidence (%)			Intensity			Order of appearance		
	70% O_2, 30% CO_2	100% CO_2	100% N_2	70% O_2, 30% CO_2	100% CO_2	100% N_2	70% O_2, 30% CO_2	100% CO_2	100% N_2
Aromatic									
Porky	97.2	98.8	100.0	6.50	6.54	6.65	1.38	1.41	1.38
Livery	66.7	76.2	78.1	1.29^{a}	0.94^{b}	0.99^{b}	3.85	3.88	3.59
Browned	91.7	79.8	89.1	0.94	0.85	0.98	1.97	1.96	1.85
Metallic	36.1	35.7	32.8	0.79	0.57	0.71	3.86	4.12	4.38
Fatty	58.3	57.1	62.5	0.52^{a}	0.46^{a}	0.36^{b}	3.52	3.50	3.89
Off	8.3^{ab}	4.8^{b}	14.1^{a}	1.60	2.75	2.32	1.00	1.00	1.00
Chemical sour	11.1	13.1	10.9	2.86	3.04	2.49	1.04	1.03	1.08
Barnyard	8.3^{b}	22.6^{a}	25.0^{a}	2.49^{b}	3.17^{ab}	3.76^{a}	1.00	1.00	1.00
Sour/barnyard	44.4	42.9	39.1	3.52	3.69	3.68	1.00	1.00	1.00
Barnyard/urine	23.6^{a}	20.7^{b}	6.2^{b}	5.89	4.84	4.12	1.00	1.00	1.00
Chemical/barnyard/sour	4.2	6.0	4.7	3.74	3.60	3.73	1.47	0.91	1.24
Singed	2.8^{ab}	0.0^{b}	6.4^{a}	1.17	—	0.74	2.00	—	2.00
Tastes									
Sweet	97.2	98.8	100.0	2.16	2.18	2.20	3.13	3.05	3.10
Salt	97.2	98.8	100.0	1.96	2.06	2.06	4.13	4.05	4.10
Sour	97.2	98.8	100.0	2.86	2.93	2.96	5.09^{a}	4.96^{b}	5.11^{a}
Bitter	72.2	75.0	67.2	0.73	0.82	0.66	6.09	5.91	6.03
Mouthfeelings									
Temperature	100.0	100.0	100.0	9.04	9.10	9.12	2.09	2.04	2.05
Astringent	72.2	76.2	73.4	0.70	0.85	0.81	4.72	4.49	4.60
Aftertastes/afterfeelings									
Porky	97.2	98.8	100.0	5.57	5.56	5.66			
Sweet	97.2	98.8	100.0	1.51	1.51	1.53			
Salt	97.2	98.8	100.0	1.48	1.57	1.49			
Sour	97.2	98.8	100.0	2.29	2.33	2.27			
Bitter	69.4	84.5	65.6	0.77	0.76	0.85			
Livery	63.9	72.6	73.4	1.00^{a}	0.72^{b}	0.82^{ab}			
Fatty	47.2	57.1	51.6	0.49^{a}	0.42^{ab}	0.34^{b}			
Browned	62.5	53.6	64.1	0.51	0.49	0.53			
Metallic	36.1	38.1	34.4	0.80	0.68	0.69			
Off	34.7	29.8	45.3	1.72	1.43	1.61			
Chemical sour	18.1^{ab}	21.4^{a}	9.4^{b}	1.65	2.03	1.44			
Barnyard	13.9^{b}	22.6^{ab}	26.6^{a}	2.21^{b}	2.01^{b}	3.13^{a}			
Sour barnyard	16.7	17.9	10.9	3.34	2.90	2.63			
Chemical/barnyard/sour	2.8	2.4	6.2	2.55	2.06	2.54			
Barnyard/urine	9.7^{a}	6.0^{ab}	1.6^{b}	6.99^{a}	0.58^{b}	1.19^{b}			
Astringent	54.2	72.6	65.6	0.59	0.65	0.66			
Chemical bite	4.2	1.2	1.6	0.61	0.83	0.50			
Singed	2.8	0.0	0.0	1.25	—	—			
Amplitude				6.64	6.85	6.68			

*Generated by 6 to 12 highly trained profile panelists.
[a,b,c]Means in the same row without a superscript or bearing a common superscript do not differ significantly ($P \geq 0.05$).

$R^2 = 0.86$, respectively), bitter taste ($P \leq 0.05$, $R^2 = 0.63$) and bitter, unidentifiable 'off', and chemical sour aftertastes ($P \leq 0.01$, $R^2 = 0.82$; $P \leq 0.05$, $R^2 = 64$; and $P \leq 0.05$, $R^2 = 0.61$), indicating these unusual and undesirable traits increased progressively in intensity as storage was extended. Therefore, normal character notes generally became less prevalent and less intense and were detected later as storage time increased, and unusual character notes generally became more prevalent and more intense and were perceived earlier as storage time increased. Consequently, a significant negative time trend with storage time was detected in flavor amplitude ($P \leq 0.01$, $R^2 = 0.91$), indicating the normality, balance, and blendedness of the overall flavor deteriorated progressively during storage, and storage time accounted for 91% of the variation in flavor amplitude, when the data were pooled over storage atmospheres and storage temperatures.

DISCUSSION

Recent studies have indicated it should be possible to extend the chilled storage life of pork primals to facilitate all domestic and export applications, if contamination of the commercial product with spoilage organisms,

Table 5. Flavor profiles of samples stored at different temperatures*

Character note	Incidence (%)			Intensity			Order of appearance		
	−1.5	2	5	−1.5	2	5	−1.5	2	5
Aromatic									
Porky	98.8	97.2	100.0	6.56	6.58	6.55	1.41	1.38	1.38
Livery	71.3	72.2	77.9‡	1.01	1.07	1.15	3.72	3.74	3.86
Browned	87.5	87.5	83.8‡	0.91[ab]	0.81[b]	1.04[a]	2.13[a]	2.06[a]	1.59[b]
Metallic	33.8	33.3	38.2‡	0.77	0.66	0.65	3.97	4.29	4.10
Fatty	61.2	56.9	58.8	0.47	0.40	0.46	3.45	3.72	3.73
Off	7.5	9.7	8.8	2.02	2.35	2.31	1.00	1.00	1.00
Chemical sour	13.8	8.3	13.2	2.80	2.70	2.89	1.00	1.05	1.10
Barnyard	16.2	20.8	19.1	3.20	3.26	2.96	1.00	1.00	1.00
Sour/barnyard	36.2	45.8	45.6	3.47	3.89	3.52	1.00	1.00	1.00
Barnyard/urine	18.8	11.1	10.3	4.89	5.22	4.75	1.00	1.00	1.00
Chemical/barnyard/sour	7.5	4.2	2.9	3.74	4.10	3.23	0.87	1.54	1.21
Singed	2.5[a]	2.8[a]	0.0[b]	1.17	0.74	—	2.00	2.00	—
Tastes									
Sweet	98.8	97.2	100.0†	2.16	2.20	2.18	3.10	3.09	3.08
Salt	98.8	97.2	100.0†	2.02	2.01	2.05	4.10	4.09	4.08
Sour	98.8	97.2	100.0†	2.90	2.89	2.93	5.04	5.08	5.04
Bitter	73.8	66.7	75.0	0.71	0.79	0.70	5.97	6.03	6.04
Mouthfeelings									
Temperature	100.0	100.0	100.0	9.06	9.08	9.13	2.07	2.05	2.06
Astringent	76.2	70.8	75.0	0.71	0.79	0.86	4.59	4.67	4.56
Aftertastes/afterfeelings									
Porky	98.8	97.2	100.0	5.59	5.64	5.57			
Sweet	98.8	97.2	100.0	1.52	1.54	1.49			
Salt	98.8	97.2	100.0	1.55	1.51	1.49			
Sour	98.8	97.2	100.0	2.33	2.30	2.26			
Bitter	72.5	72.2	77.9	0.74	0.86	0.79			
Livery	66.2	68.1	76.5‡	0.82	0.75	0.97			
Fatty	56.2	47.2	52.9	0.46	0.36	0.42			
Browned	57.5	55.6	66.2‡	0.53	0.47	0.53			
Metallic	33.8	37.5	38.2	0.85	0.62	0.70			
Off	35.0	31.9	41.2	1.69	1.58	1.49			
Chemical sour	15.0	12.5	23.5†	1.52	1.96	1.64			
Barnyard	21.2	26.4	14.7	2.29	2.17	2.90			
Sour/barnyard	13.8	18.1	14.7	2.68	3.01	3.17			
Chemical/barnyard/sour	6.2[a]	0.0[b]	4.4[a]	1.81	—	2.95			
Barnyard/urine	6.2	6.9	4.4	4.51	2.50	1.78			
Astringent	68.8	58.3	66.2	0.58	0.62	0.70			
Chemical bite	5.0[a]	1.4[a]	0.0[b]	0.67	0.50	—			
Singed	1.2	1.4	0.0	2.00	0.50	—			
Amplitude				6.69	6.78	6.70			

*Generated by 6 to 12 highly trained profile panelists.
[a,b,c]Means in the same row without a superscript or bearing a common superscript do not differ significantly ($P \geq 0.05$).
†($P > 0.05$) trend.
‡$P < 0.01$ trend.

including lactics, can be sufficiently restricted to preclude early attainment of maximum numbers (Jeremiah *et al.*, 1992*a*, 1995*a*,*b*; Jeremiah and Gibson, 1995).

Chilled red meats have been observed to become increasingly tender and to finally lose their desirable textural characteristics during prolonged storage under vacuum or carbon dioxide (Gill, 1988). The autolytic activities associated with such textural changes have also been observed to produce aged 'liver-like' flavors, which in time reach intensities objectionable to consumers (Gill, 1988). Since pork muscle generally has less muscle pigment and tenderizes more rapidly than other red meats (Dransfield *et al.*, 1980, 1981) and pork lipids are more susceptible to oxidative rancidity (Ordonez and Ledward, 1977), it would be reasonable to assume non-microbial deterioration would occur more readily in pork than in other red meats. Moreover, Bruce *et al.* (1992) reported textural defects (fissures) in beef stored in 100% carbon dioxide controlled atmospheres which they attributed to evolution of absorbed carbon dioxide from the meat during cooking. However, in another study, pork texture was reported to remain largely unaltered during chilled storage in 100% carbon

Table 6. Flavor profiles of samples stored for different intervals*

Incidence (%)

Character note	0	4	8	12	16	20	24
Aromatics							
Porky	100.0	100.0	100.0	100.0	97.2	100.0	90.0
Livery	77.8	83.3	77.8	75.0	66.7	60.0	65.0‡
Browned	94.4^{a}	94.4^{a}	86.1^{ab}	94.4^{a}	77.8^{ab}	80.0^{ab}	65.0^{b‡}
Metallic	16.7^{a}	19.4^{a}	27.8^{bc}	33.3^{b}	52.7^{a}	55.0^{a}	60.0^{a‡}
Fatty	86.1^{a}	72.2^{a}	47.2^{b}	63.9^{ab}	47.2^{bc}	35.0^{c}	45.0^{bc†}
Off	11.1^{ab}	19.4^{a}	5.6^{b}	11.1^{ab}	5.6^{b}	0.0^{c}	0.0^{c‡}
Chemical sour	19.4^{a}	11.1^{ab}	16.7^{ab}	11.1^{ab}	8.3^{b}	0.0^{c}	10.0^{ab}
Barnyard	25.0^{ab}	13.9^{bc}	30.6^{a}	11.1^{c}	5.6^{c}	20.0^{a}	30.0^{a}
Sour/barnyard	44.4^{ab}	52.8^{a}	38.9^{ab}	38.9^{ab}	41.7^{ab}	45.0^{ab}	30.0^{b}
Barnyard/urine	0.0^{d}	2.8^{cd}	5.6^{c}	16.7^{b}	33.3^{a}	20.0^{ab}	25.0^{ab‡}
Chemical/barnyard/sour	0.0^{d}	0.0^{d}	2.8^{cd}	11.1^{ab}	5.6^{bc}	15.0^{a}	5.0^{bc}
Singed	0.0^{c}	0.0^{c}	0.0^{c}	0.0^{c}	2.8^{bc}	10.0^{a}	5.0^{ab}
Tastes							
Sweet	100.0	100.0	100.0	100.0	97.2	100.0	90.0
Salt	100.0	100.0	100.0	100.0	97.2	100.0	90.0
Sour	100.0	100.0	100.0	100.0	97.2	100.0	90.0
Bitter	63.9	50.0	83.3	63.9	91.7	75.0	80.0
Mouthfeelings							
Temperature	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Astringent	75.0	66.7	69.4	77.8	80.6	90.0	60.0
Aftertaste/afterfeelings							
Porky	100.0	100.0	100.0	100.0	97.2	100.0	100.0
Sweet	100.0	100.0	100.0	100.0	97.2	100.0	90.0
Salt	100.0	100.0	100.0	100.0	97.2	100.0	90.0
Sour	100.0	100.0	100.0	100.0	97.2	100.0	90.0
Bitter	77.8^{ab}	55.6^{b}	77.8^{ab}	69.4^{ab}	83.3^{a}	85.0^{a}	75.0^{ab}
Livery	63.9^{b}	88.9^{a}	69.4^{ab}	72.2^{ab}	66.7^{ab}	55.0^{b}	65.0^{ab}
Fatty	66.7^{a}	63.9^{ab}	50.0^{abc}	55.6^{ab}	36.1^{cd}	25.0^{d}	45.0^{bc†}
Browned	83.3^{a}	66.7^{a}	61.1^{ab}	61.1^{ab}	41.7^{b}	45.0^{b}	45.0^{b‡}
Metallic	16.7^{cd}	8.3^{d}	25.0^{c}	41.7^{b}	61.1^{ab}	60.0^{ab}	65.0^{a‡}
Off	44.4^{a}	41.7^{a}	44.4^{a}	44.4^{a}	13.9^{c}	30.0^{ab}	25.0^{bc†}
Chemical sour	25.0^{a}	22.2^{a}	25.0^{a}	13.9^{ab}	13.9^{ab}	5.0^{b}	0.0^{c‡}
Barnyard	22.2^{a}	22.2^{a}	22.2^{a}	19.4^{ab}	19.4^{ab}	10.0^{b}	30.0^{a}
Sour/barnyard	11.1^{c}	13.9^{bc}	2.8^{d}	11.1^{c}	33.3^{a}	25.0^{abc}	15.0^{bc}
Chemical/barnyard/sour	0.0^{c}	0.0^{c}	2.8^{bc}	2.8^{bc}	8.3^{ab}	15.0	0.0^{c}
Barnyard/urine	0.0^{b}	0.0^{b}	0.0^{b}	8.3^{a}	11.1^{a}	15.0^{a}	15.0^{a‡}
Astringent	63.9	61.1	58.3	58.3	77.8	75.0	60.0
Chemical bite	0.0^{b}	2.8^{b}	0.0^{b}	2.8^{b}	2.8^{b}	10.0^{a}	0.0^{b}
Singed	0.0^{b}	0.0^{b}	0.0^{b}	0.0^{b}	0.0^{b}	5.0^{a}	5.0^{a†}
Amplitude							

Intensity

Character note	0	4	8	12	16	20	24
Aromatics							
Porky	6.96^{a}	7.04^{a}	6.79^{a}	6.78^{a}	6.05^{bc}	6.40^{b}	5.94^{c‡}
Livery	1.02	1.01	1.20	1.02	0.86	1.27	1.15
Browned	1.06	0.99	1.06	0.91	0.81	0.76	0.86‡
Metallic	0.66	0.53	0.57	0.60	0.77	0.74	0.97‡
Fatty	0.54^{ab}	0.62^{a}	0.38^{cd}	0.48^{bc}	0.31^{d}	0.39^{bcd}	0.37^{bcd†}
Off	2.16	2.08	2.50	2.03	2.35	—	—
Chemical sour	2.45	2.81	3.22	2.21	3.73	—	2.37
Barnyard	3.36^{b}	2.59^{b}	3.35^{b}	2.61^{b}	2.52^{b}	2.74^{b}	4.81^{a}
Sour/barnyard	3.21^{b}	3.09^{b}	3.53^{b}	3.33^{b}	3.63^{b}	3.56^{b}	5.02^{a†}
Barnyard/urine	—	1.30	3.96	3.18	6.91	6.15	8.22†
Chemical/barnyard/sour	—	—	3.59	4.02	3.93	3.90	3.01
Singed	—	—	—	—	0.80	1.17	0.67
Tastes							
Sweet	2.41^{ab}	2.44^{a}	2.40^{ab}	2.23^{b}	1.93^{c}	1.95^{c}	1.89^{c‡}
Salt	2.23^{a}	2.15^{ab}	2.08^{b}	2.02^{bc}	1.91^{c}	1.91^{c}	1.89^{c†}
Sour	2.98^{ab}	2.72^{bc}	2.99^{ab}	2.61^{c}	3.11^{a}	2.80^{abc}	3.21^{a}
Bitter	0.58	0.63	0.66	0.86	0.81	0.85	0.76†
Mouthfeelings							
Temperature	9.09^{a}	9.02^{b}	9.07^{b}	9.14^{b}	9.10^{b}	8.87^{c}	9.33
Astringent	0.60^{d}	0.75^{bcd}	0.80^{abc}	0.65^{cd}	0.97^{a}	0.84^{abc}	0.91^{ab}
Aftertaste/afterfeelings							
Porky	6.00^{ab}	6.11^{a}	5.72^{bc}	5.81^{abc}	5.03^{c}	5.44^{cd}	5.08^{abc‡}
Sweet	1.69^{a}	1.70^{a}	1.66^{a}	1.62^{a}	1.24^{b}	1.42^{b}	1.31^{b‡}
Salt	1.72^{a}	1.58^{abc}	1.61^{ab}	1.55^{bc}	1.36^{d}	1.35^{d}	1.42^{cd‡}
Sour	2.30^{ab}	2.02^{c}	2.33^{ab}	2.14^{bc}	2.49^{a}	2.23^{abc}	2.56^{a}
Bitter	0.54^{c}	0.70^{bc}	0.68^{bc}	0.88^{ab}	0.81^{b}	0.88^{ab}	1.07^{a‡}
Livery	0.81	0.76	0.87	0.84	0.72	1.04	0.90
Fatty	0.42^{b}	0.58^{a}	0.34^{b}	0.45^{b}	0.31^{b}	0.44^{ab}	0.36^{b}
Browned	0.58	0.55	0.63	0.58	0.50	0.37	0.37‡
Metallic	0.70	0.78	0.47	0.70	0.75	0.81	0.85
Off	1.34^{bc}	1.09^{c}	1.49^{bc}	1.39^{bc}	1.87^{ab}	1.46^{bc}	2.48^{a†}
Chemical sour	1.36	1.56	1.40	1.46	2.39	2.07	—†
Barnyard	1.65^{c}	1.80^{c}	2.04^{bc}	2.24^{bc}	3.55^{a}	2.76^{abc}	3.13^{ab}
Sour/barnyard	1.92^{cd}	2.43^{cd}	6.00^{a}	2.07^{cd}	2.66^{c}	1.70^{d}	3.90^{b}
Chemical/barnyard/sour	—	—	3.41	0.44	2.84	2.84	—
Barnyard/urine	—	—	—	2.20	7.07	5.51	2.24
Astringent	0.51	0.59	0.67	0.52	0.76	0.66	0.72
Chemical bite	—	0.50	—	0.67	0.83	0.59	—
Singed	—	—	—	—	—	2.00	0.50
Amplitude	7.75^{a}	7.78^{a}	7.31^{ab}	6.90^{bc}	5.82^{cd}	6.31^{cd}	5.20^{c‡}

Order of appearance

Character note	0	4	8	12	16	20	24
Aromatics							
Porky	1.17^{d}	1.08^{d}	1.33^{cd}	1.25^{cd}	1.60^{ab}	1.58^{abc}	1.71^{a‡}
Livery	3.44	3.64	3.59	3.90	3.61	4.26	3.98†
Browned	1.87	1.70	1.99	1.73	1.84	2.56	1.79
Metallic	3.76	4.78	4.51	4.12	4.22	3.44	4.01
Fatty	3.39^{bc}	3.21^{c}	3.28^{bc}	3.43^{bc}	3.86^{ab}	3.75^{abc}	4.53^{a‡}
Off	1.00	1.00	1.00	1.00	1.00	—	—
Chemical sour	1.01	1.22	1.01	0.99	1.00	—	1.00
Barnyard	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Sour/barnyard	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Barnyard/urine	—	1.00	1.00	1.00	1.00	1.00	1.00
Chemical/barnyard/sour	—	—	1.30	1.19	1.19	1.41	0.96
Singed	—	—	—	—	1.00	2.00	3.00
Tastes							
Sweet	3.06^{a}	3.00^{b}	3.06^{b}	3.06^{b}	3.11^{b}	3.06^{b}	3.29^{a†}
Salt	4.06^{b}	4.00^{b}	4.06^{b}	4.06^{b}	4.11^{b}	4.06^{b}	4.29^{a†}
Sour	5.06^{b}	4.97^{b}	4.96^{b}	5.06^{b}	4.03^{b}	4.99^{b}	5.32^{a}
Bitter	5.92	5.88	5.85	6.07	5.94	6.05	6.32†
Mouthfeelings							
Temperature	2.03	2.00	2.06	2.06	2.06	2.06	2.17†
Astringent	4.86	4.50	4.46	4.59	4.42	4.88	4.54

*Generated by 6 to 12 highly trained profile panelists.

$^{a-e}$Means in the same row without a superscript or bearing a common superscript do not differ significantly ($P \geq 0.05$).

$^{\dagger}P < 0.05$ trend.

$^{\ddagger}P < 0.01$ trend.

dioxide, except the texture became progressively drier during prolonged storage (Jeremiah *et al.*, 1992*a*). In addition, the desirable, progressive tenderization observed in other red meats (Gill, 1988) was not observed with pork (Jeremiah *et al.*, 1992*a*,*b*). The fact fissures, such as those reported by Bruce *et al.* (1992) were not detected in other studies (Jeremiah, *et al.*, 1992*a*,*b*; Jeremiah and Gibson, 1995) would appear due to differences in the carbon dioxide levels in the package during storage. Bruce *et al.* (1992) employed a carbon dioxide level of 5 liters/kg, while a level of 1 to 2 liters/kg were employed in the other studies. The optimum level of carbon dioxide to use to extend chilled storage life of red meats and pork has been reported to be 1 to 2 liters/kg (Gill and Penney, 1988) and 2 liters/kg (Jeremiah *et al.*, 1996), respectively.

The limiting factor for extension of chilled storage life, at the present time, has been reported to be early off-flavor development arising from a flora of predominantly lactic acid bacteria, which reach maximum numbers between six and nine weeks in pork stored at −1.5°C in a controlled atmosphere of 100% CO_2 (Jeremiah and Gibson, 1995).

Optimally, pork flavor contains only appropriate flavor character notes or notes usually associated with fresh (unstored) pork with normal (neither pale, soft, and exudative (PSE) nor dark, firm, dry (DFD)) characteristics in the proper balance and blend to provide a favorable overall impression and a high flavor amplitude ($\geq$ 7.50) (Jeremiah and Gibson, 1995). Since pork is a biological rather than manufactured product, some unusual flavor character notes are likely to be present. However, they should be relatively low in both incidence and intensity, so that they tend to be masked by the normal notes to the untrained consumer. Pork with these characteristics would be exemplified by unstored samples with reduced initial microbial contamination and, to a lesser extent, by unstored samples with commercial initial microbial contamination (Jeremiah and Gibson, 1995).

In a previous study, the flavor of pork with commercial microbial contamination deteriorated progressively during storage and was slightly unusual, unbalanced, and unblended (flavor amplitude = 6.83) following only six weeks of storage (Jeremiah and Gibson, 1995), which is consistent with other reports of off-flavor development starting at five weeks of storage in pork with commercial microbial contamination (Jeremiah *et al.* 1992*a*,*b*, 1995*a*,*b*). In contrast, the flavor of pork with reduced microbial contamination remained normal, well balanced, and well blended (flavor amplitude $\geq$7.50) until after 24 weeks of storage, when it was only slightly unusual, unbalanced, and unblended (flavor amplitude = 6.00) (Jeremiah and Gibson, 1995). Consequently, early off-flavor development was primarily due to unusual sour/off and barnyard character notes emerging after six weeks of chilled (−1.5°C) storage of pork primals with commercial microbial contamination, which became progressively more intense, in a steadily increasing proportion of samples, which coincided with lactics reaching maximum numbers (Jeremiah and Gibson, 1995). Egan, (1983) and Borch and Agerhem, (1992) also reported lactic acid bacteria were capable of spoiling meat through a progressive increase in sourness, after lactics had reached maximum numbers.

In the present study, storage atmosphere and temperature exerted little influence on flavor and texture properties, when data were pooled over storage time and storage atmosphere or storage temperature. However, both flavor and texture deteriorated progressively as storage was extended and storage time accounted for 94 and 91%, respectively, of the variation in texture and flavor amplitude ratings, when data were pooled over storage atmospheres and storage temperatures. Appropriate flavor character notes became less prevalent and less intense and were detected later, while unusual flavor character notes became more prevalent and more intense and were detected earlier, as storage was extended, resulting in the flavor of samples becoming unusual, unbalanced, and unblended after 12 days of storage, when data were pooled over storage atmospheres and storage temperatures. Consequently, off-flavor development constituted the limiting factor in extending the chilled storage life of display-ready pork in controlled atmosphere masterpacks. The fact that previous research indicated off-flavor development coincided with lactic acid bacteria attaining maximum numbers (Jeremiah *et al.*, 1992*a*; Jeremiah and Gibson, 1995) indicates that, if the chilled storage life of pork is to be extended beyond the limits defined by present research, it will be necessary to substantially improve the microbiological quality of the commercial product.

Despite the higher susceptibility of pork lipids to oxidative rancidity (Ordonez and Ledward, 1977), rancid flavor changes in pork stored under controlled or vacuum atmospheres in the present and previous studies (Jeremiah *et al.*, 1992*a*,*b*; Jeremiah and Gibson, 1995), indicate rancidity should not constitute a problem if films of very low oxygen permeability are utilized and temperature abuse does not occur.

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APPENDIX

Definition of Flavor Character Notes

Porky	The aromatic and/or aftertaste associated with cooked pork.
Livery	The aromatic and/or aftertaste associated with cooked liver.
Browned	The aromatic and/or aftertaste associated with carmelization of the meat surface during cooking.
Metallic	The aromatic and/or aftertaste associated with the sensation perceived from sucking on a nickel or consuming water with a high iron content.
Fatty	The aromatic and/or aftertaste associated with cooked pork fat.
Off	The aromatic and/or aftertaste perceived as an unusual 'off' sensation, which cannot be readily identified.
Chemical sour	The aromatic and/or aftertaste associated with an acidic chemical.
Barnyard	The aromatic and/or aftertaste associated with the sensation perceived in a barnyard.
Sour/barnyard	The aromatic and/or aftertaste associated with the sensations perceived from an acidic compound and a barnyard in combination.
Barnyard/urine	The aromatic and/or aftertaste perceived from urine and a barnyard in combination.
Chemical/barnyard/sour	The aromatic and/or aftertaste associated with the perception of an acidic chemical compound and a barnyard in combination.
Singed	The aromatic and/or aftertaste associated with the sensation perceived from singed hair.
Sweet	The taste or aftertaste associated with consuming a sucrose solution.
Salt	The taste or aftertaste associated with consuming a sodium chloride solution.
Sour	The taste or aftertaste associated with consuming a citric acid solution.
Bitter	The taste or aftertaste associated with consuming a caffeine solution.
Temperature	The mouthfeeling associated with the amount of physical (thermal) heat in the sample.
Astringent	The mouthfeeling and/or afterfeeling perceived as dryness in the presence of moisture.
Chemical bite	The mouthfeeling and/or afterfeeling perceived as a biting sensation associated with consuming 'hot' peppers.
Amplitude	The overall impression of the normality, balance, and blendedness of the individual character notes.