Lipid-Soluble Components of Meat Flavors/Odors and Their Biochemical Origin[1]

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ABSTRACT

A review of the lipid-soluble constituents important in the flavor-odor of various meats is presented. In addition, the focus of current research at The Pennsylvania State University in these areas is discussed. Special emphasis is given to the flavor of aged beef, swine sex odor, mutton flavor, turkey-chicken skin flavor, and mechanically deboned turkey-chicken flavor. The data presented include both chemical analyses and the results of sensory evaluation. Metabolic pathways and biochemical mechanisms in the formation of meat flavor-odor components are presented and discussed.

INTRODUCTION

Perhaps no characteristic of meat and meat products, with the possible exception of tenderness, is so important to consumer acceptance as is flavor (1). Although this acceptance involves all the consumer's senses, especially taste and smell, the relative importance and contribution of each is still in doubt (2). Thus, the subject of meat flavors is of interest to the psychologist and sociologist as well as the meat scientist and chemist.

Meat flavor studies have emphasized both the water-soluble components associated with the lean portion, and the lipid-soluble components associated with the fat portion of the meat from the various species of domestic animals used for food (3). Hornstein and Crowe (4,5), based upon a rather extensive and comprehensive series of studies conducted in the U.S. Department of Agriculture's Meat Laboratory, suggested that the lean portion contributes a basic meaty flavor that is practically identical in beef, pork, and lamb, whereas the fat portion contributes the unique flavor that characterizes the meat from these species. A recent review of poultry flavor (6) would appear to suggest that the same generalization can be applied to the two major avian meat species, chickens and turkeys.

Subscribing to this general, but perhaps too simplistic, view of meat flavor from both animal and avian sources, we have focused our attention on the lipid-soluble flavor components. Thus, the purpose of this paper is to summarize some of our work on the chemical and sensory aspects of these constituents from both red meat and poultry meat species.

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TABLE I

Amount of Carbonyl Compounds (μM/g Lipid) Isolated from Aged Beef Ribs (*M. longissimus dorsi*). (13)

Carbonyl compounds	Aging period (days)			
	0	3	8	14
Total carbonyls	6.50	11.02	11.61	17.94
Monocarbonyls	1.69	4.51	4.46	6.26
Alk-2-ones	0.89	3.82	3.78	5.44
Alkanals	0.00	0.02	0.02	0.03
Alk-2-enals	0.04	0.02	0.02	0.01

FLAVOR STUDIES OF AGED BEEF

Much of the meat flavor research with beef has been associated with either fresh or cooked samples (3). However, a significant portion of beef supplies are aged to produce a distinctive flavor. Although Howe and Barbella (7) reported some early efforts investigating the flavor of meat during aging, it is rather surprising that subsequent research interest in this area has been practically nonexistent.

Herz and Chang (3) have indicated that the most numerous members of any class of compounds identified in meat flavor concentrates are the carbonyls. Although there are both water- and fat-soluble carbonyls, Sanderson et al. (8) indicated those involved in meat flavor are primarily lipid-soluble. Since the degradation of lipid compounds has been associated with flavor development (9) and with the aging of meat (10), it seems reasonable to suggest a relationship between the two. The now classical work of Patton et al. (11) established the unsaturated C-18 fatty acids as precursors of carbonyls. A subsequent study in our laboratory (12) reported on the considerable quantities of these fatty acids in beef and on their changes during low temperature storage. Logically then, the carbonyls can be implicated in the flavor of aged beef.

We reported an initial study on the changes in the carbonyls of beef during aging (13). The concentrations of the carbonyl classes isolated from the beef ribs at the various aging times are presented in Table I. Fresh (0 day) sample values are in general agreement with the limited quantitative data available (14). What is immediately evident is the sharp increase in most of the carbonyl classes. After only 3 days of aging, the total carbonyl content was almost twice that present at slaughter whereas the amont of monocarbonyls had increased approximately 3 times. Both classes of carbonyls did not appreciably increase in amount between 3 and 8 days of aging. However, after 14 days, the total carbonyls present represented about a threefold increase over the amount initially present (0 day), and the monocarbonyls showed almost a fourfold increase. The alk-2-ones (methyl ketones) constituted the largest group of monocarbonyls. An absolute increase in the alk-2-ones from 0.89 μM/g lipid initially present to 5.44 μM/g lipid at the end of the trial was noted. This represents more than a sixfold increase. As with the mono- and total carbonyls, very little change in the amount of alk-2-ones between 3 and 8 days aging was observed.

Although isolated in small quantities, the amount of alkanals was noted to increase whereas the alk-2-enal content appeared to decrease during aging.

Although the data demonstrate dramatic changes in the lipid-soluble carbonyls of beef muscle during aging, the flavor significance of these findings is yet to be determined. As Herz and Chang (3) have noted, the role carbonyl compounds play in meat flavor is not yet clear. Although they may be the principal flavor constituents, they also could react with other compounds present to form important secondary flavor products. Work is now projected to determine the specific chemical composition of each carbonyl fraction or class and to relate these observations to taste panel evaluations.

Under the usual conditions of aging beef, it is likely that autoxidation of fatty acids, particularly the C-18 unsatu-

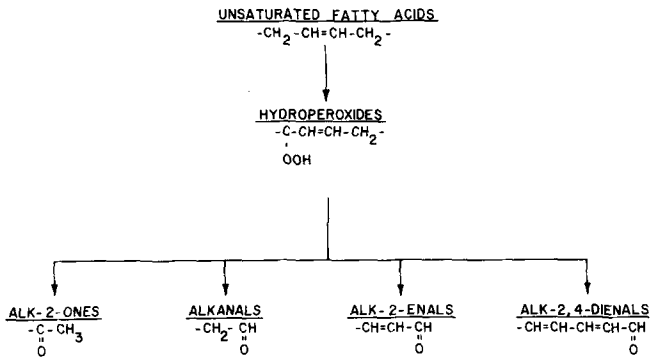

FIG. 1. Metabolic pathway for the formation of carbonyl compounds via autoxidation. (6)

rates, via hydroperoxides, as shown in Figure 1, can produce alkanals, alk-2-enals, alk-2,4-dienals, and perhaps even alk-2-ones (6). However, for the latter, the evidence generally suggests nonoxidative formation from the 3-keto acids of certain triglycerides (15). Carbonyl compounds can also be produced by microorganisms, particularly *Pseudomonas fragi* (16), which are one of the dominant species found on beef carcasses and cuts (17). Smith and Alford (16) have shown that *P. fragi* can produce comparatively copious amounts of alkanals, alk-2-enals and alk-2-ones, but apparently completely destroy the alk-2,4-dienals. *Staphylococcus aureus* has been observed to decrease the alkanal and alk-2-enal content in meat by 44 and 66%, respectively (18). Such actions could explain the carbonyl production pattern observed in our experiments (13).

STUDIES ON SWINE SEX ODOR

Interest and research in the volatile compounds that give rise to the characteristic odor(s) distinctive of a particular food product have been quite extensive in recent years. One that has received particular attention is the distinctive and displeasing odor obtained when heating the flesh of intact males (boars) or other swine tissue containing sex odor (SSO). This distinctive odor has been described as onion-like, urine-like, and perspiration-like (19,20), and is characteristic of most boar carcasses. However, other types of swine carcasses (21) also possess SSO. Craig et al. (20) established that the odor was definitely associated with the fatty tissues of the boar carcass and more importantly that the compounds were concentrated in the nonsaponifiable fraction (NSF) of the fat.

The theoretical aspects of SSO were first formulated by Sink (22) who proposed that the odor was caused by C_{19}-16-ene steroids. Patterson (23) reported the presence of 5α-androst-16-en-3-one in the high vacuum volatile strippings from boar fat and indicated it was responsible for SSO. Later work in our laboratory reported that both the 3-keto and 3-hydroxy C_{19}-16-ene steroids were involved (24). Subsequent work using multidetection methods (GLC-MS) confirmed the presence of 5α-androst-16-en-3-one and reported the presence of 3α-hydroxy-5α-androst-16-ene (see Fig. 2 [25,26]). There now seems little doubt that these C_{19}-16-ene steroids, particularly the 3-ketone, are responsible for SSO.

A unique aspect of SSO is the variation in and possible human sex-related ability to perceive this odor. To some consumers, the presence of SSO is not unacceptable, while to others the slightest hint of this odor is enough to cause serious objection and, many times, rejection. We have noted that some people are consistently able to perceive small amounts of the odor, while others cannot detect any odor. This phenomenon may originate with some favorable or unfavorable conditioning to SSO. However, Griffiths and Patterson (27) noted a sex-related difference in the ability to detect 5α-androst-16-en-3-one. They found that 92% of

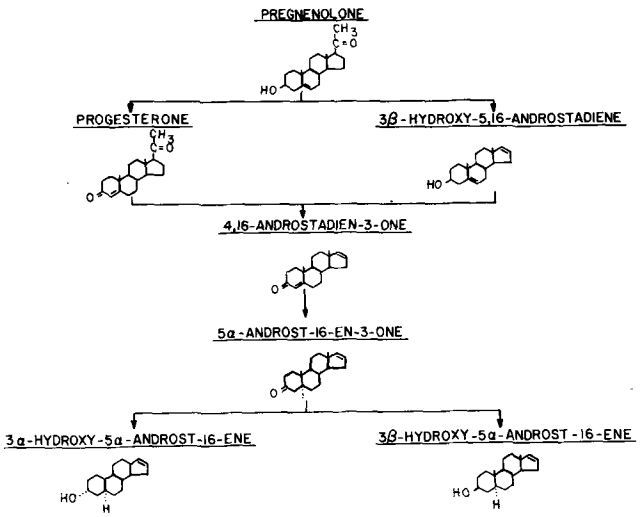

FIG. 2. Metabolic pathways for the formation of the C_{19}-16-ene steroids. (28)

the women but only 46% of the men tested could smell this steroid.

Perhaps the most extensive and comprehensive work on the biosynthesis of the C_{19}-16-ene steroids is that of Gower and his coworkers, and an excellent review has been published recently (28). Essentially they have established the formation of these steroids in boar testis tissue from pregnenolone, as shown in Figure 2. Of the 2 pathways to 4,16-androstadien-3-one, the one via 3β-hydroxy-5,16-androstadiene appears to be the most preferred. Gower (28) has indicated that such a pathway may be unique in steroid biochemistry. Earlier (22), we had suggested pregnenolone as the key precursor of C_{19}-16-ene steroids in both testicular and adrenal cortical tissue. However, compared with the testes, the adrenal cortex is a less efficient producer of these odorous steroids (28).

STUDIES ON MUTTON FLAVOR

The characteristic flavor of sheep meat has been cited as the reason for its low consumption, less than 1.6% of the total amount of red meat eaten (29). Although Wasserman and Talley (30) reported that the flavor of lamb is so characteristic it can be identified by people with little previous exposure, the distinction between the "characteristic" flavors of lamb and mutton meat has not been well defined. People apparently differ in their concept of what constitutes mutton flavor. Mutton meat may have an entirely different flavor, or may merely represent a change in concentration. The ability to distinguish between lamb and mutton flavors varies among people. In preliminary studies on threshold tests, Batcher et al. (31) found 3 out of 14 people tested were able to detect mutton flavor in ground lamb patties containing 15% mutton; 7 were able to detect the flavor in patties containing 15-35% mutton, and the remaining 4 people required more than 35% mutton in the patties before the presence of mutton flavor was detected.

Hofstrand and Jacobson (32) had noted an indication that fat may contribute to the flavor of lamb and mutton broths. They observed that the depot fats were found to have flavor components. They later reported (33) that volatile stripping, under vacuum at 80 C, resulted in a yellow oily concentrate. IR analysis of the concentrates showed the presence of both aliphatic and conjugated carbonyl compounds. Subsequent class separation demonstrated the monocarbonyls (alkanals and alk-2-ones), as opposed to the polycarbonyls, predominate. Hornstein and Crowe (5) reported finding alkanals in lamb fat (0.10 μM/g lipid) and that these aliphatic aldehydes were probably

TABLE II

Amount of Carbonyl Compounds (μM/10 g Lipid) Isolated from Cooked Poultry Skin Residue and Extracted Oil Stored at 40 F. (43)

	Storage time (wks)							
	0		3		5		7	
Carbonyl class	T[a]	C[a]	T	C	T	C	T	C
Total carbonyls								
Residue	111.2	145.4	nd	101.1	127.6	97.3	292.0	190.1
Oil	60.2	55.3	54.6	58.8	54.8	51.9	56.7	66.4
Monocarbonyls								
Residue	39.6	46.0	nd	29.3	24.4	26.8	34.6	36.2
Oil	3.9	4.9	6.7	2.9	4.0	5.6	4.6	7.5
Alk-2-ones								
Residue	24.3	20.1	nd	16.4	13.4	14.8	21.2	21.0
Oil	2.0	2.9	2.9	1.3	2.8	3.6	3.3	5.9
Alk-2-enals								
Residue	2.0	—	nd	1.9	3.2	1.7	10.4	2.5
Oil	0.3	0.2	0.6	0.3	0.3	0.5	0.2	0.4
Alk-2,4-dienals								
Residue	1.4	—	nd	1.5	1.2	—	2.6	0.6
Oil	—	—	0.2	—	0.2	—	0.3	0.2

nd = Not determined.

[a]T = turkey; C = chicken.

responsible for the mutton-like odor. Riley et al. (34) reported a higher monocarbonyl content in longissimus muscle than in the adjacent subcutaneous fat tissue (1.50 vs. 0.70 μM/g lipid). Analysis of the monocarbonyl fractions (0.85 μM/g) revealed the 2 components were the alkanals (0.56 μM/g) and the alk-2-enals (0.29 μM/g). Both groups (5,34) have noted that the alk-2,4-dienals and alk-2-ones are apparently not present in the fat from this meat animal species.

Lactones, as well as carbonyls, also have been found in sheep depot fats. Dimick et al. (35) noted trace amounts of C_{10}, C_{12} and C_{14} and C_{16} aliphatic delta-lactones. In addition to these lactones, Watanabe and Sato (36) also reported the presence of C_{10}, C_{12} and C_{14} gamma-lactones in small amounts. They reported the predominate delta-lactone was the C_{14} and the predominate gamma-lactone was also the C_{14} component. No quantitative data from either of these studies were reported.

Although the same autoxidation mechanism for the formation of carbonyls outlined in Figure 1 is probably operative here, the comparatively lesser amounts of the C_{18} unsaturated fatty acids, particularly the polyunsaturates, that we have observed in sheep fat (37) can probably explain the low concentration of alk-2-enals and the absence of alk-2,4-dienals. It is interesting to note that, although Riley et al. (34) reported finding ketoglycerides in sheep fat (1.38 μM/g. lipid), they could not demonstrate the presence of alk-2-ones.

Dimick et al. (38) demonstrated a δ-oxidation pathway for saturated fatty acids. They established that the 4- and 5-hydroxy fatty acids are active intermediates and thus serve as precursors for the formation of the corresponding 4- and 5-lactones. Although Swenson and Dimick (39) later questioned the 4-, 5-hydroxy fatty acids as intermediates in the δ-oxidation pathway, there is apparently no doubt as to their function as lactone precursors (40).

STUDIES ON POULTRY SKIN FLAVOR

The steadily increasing number and volume of further processed poultry products offered to consumers emphasize the expanded use of these products. Many of these newer products contain poultry lipids. The carbonyl compounds in lipid materials, as suggested by Minor et al. (41), contribute to the flavor of these foods. The economic importance of using large amounts of skin from turkeys was cited by MacNeil and Buss (42) when they noted that the skin can amount to as much as 12% of the dressed carcass weight.

Using both turkey and chicken skin and the extracted oil, experiments were initiated to compare the carbonyl composition and organoleptic evaluation as measures of product stability during various storage times. Dimick and MacNeil (43) noted that turkey and skin residues consistently contained greater quantities of carbonyls than did the corresponding oils (see Table II). They also observed that turkey skin residue contained higher concentrations of carbonyls than did the chicken samples. The oil extract from the skin of both groups was similar in carbonyl composition. Increase in storage time generally resulted in an increase in the total carbonyls but a decrease in the monocarbonyls. Thin layer chromatography of the carbonyl classes from the skin residue indicated mainly C_7-C_9 alk-2-enals and C_8-C_9 alk-2,4-dienals. Later, acetone was found to be the only alk-2-one present in skin (44).

The skin residues and oil samples were presented to a trained taste panel for flavor evaluation (45). Panel members were able to discriminate between a control (unstored) and a sample of turkey skin residue after 3 wk storage at 40 F. They were not able to differentiate between control and stored turkey skin oil samples even after 7 wk storage. When chicken skin residue and oil were evaluated after storage at 40 F, the panel members could detect differences between the residue samples at 3 wk; but, unlike the turkey oil stored at the same temperature, they indicated discriminatory ability for the chicken oil samples after 1 wk storage. When both cooked chicken and turkey skin fractions were presented to the panel at the same time without a reference control (unstored), they were able to identify differences but could not indicate a clear preference for either one.

The autoxidation of the unsaturated fatty acds, as shown in Figure 1, particularly those from phospholipids, has been suggested as the mechanism for the formation of the carbonyls found in the skin samples (6). Phospholipid phosphorus determinations indicated the skin residue contained high levels of polar lipid; whereas, negligible amounts were in the oil extract. Changes in the fatty acid composition of these residue polar lipids during storage prompted Dimick and MacNeil (43) to suggest linoleic and arachidonic acids as the probable substrates in autoxidative deterioration. It also was suggested that lipolytic species of

TABLE III

Amount of Carbonyl Compounds (μM/10 g Lipid) Isolated from Raw and Cooked Deboned Poultry Meat Stored at 3 C. (46)

	Storage time (days)							
	0		3		6		12	
Carbonyl class	T[a]	C[a]	T	C	T	C	T	C
Total carbonyls								
Raw	44.3	46.2	44.3	51.8	35.2	57.3	35.8	62.2
Cooked	138.8	91.7	90.4	123.3	108.1	55.9	262.9	81.4
Monocarbonyls								
Raw	31.8	11.1	25.4	14.1	22.6	17.6	25.3	17.5
Cooked	54.0	38.3	35.6	70.9	37.3	25.5	104.2	22.5
Alk-2-ones								
Raw	21.5	4.3	18.7	7.5	17.0	8.5	15.5	7.9
Cooked	25.2	22.3	20.4	55.5	25.5	19.5	37.1	12.3
Alk-2-enals								
Raw	0.8	0.2	1.5	0.4	0.6	0.6	1.6	0.4
Cooked	1.9	0.2	---	0.5	4.9	0.2	22.5	2.0
Alk-2,4-dienals								
Raw	0.3	0.2	0.2	0.2	0.3	0.3	0.5	0.2
Cooked	---	0.3	---	0.7	---	0.3	10.2	1.8

[a]T = turkey; C = chicken

microbes (e.g. Pseudomonas) could also be important in the production of caronyls (6). Regardless of the metabolic origin, the carbonyl compounds of the skin are important in the development of poultry flavor in cooked and processed products.

STUDIES ON MECHANICALLY DEBONED POULTRY FLAVOR

In recent years, the increased use of cut-up chicken for the fast food trade, as well as the large number of turkeys being used for turkey rolls and other convenience items has resulted in large quantities of chicken backs and necks and turkey racks of low market value. With the introduction of commercial deboning machines, it became feasible to remove the meat from necks, backs, and racks for use in further processing operations thereby increasing the market value of these raw materials and at the same time making the deboned poultry meat competitive with other types of raw meats. While the availability of this meat has opened new areas of utilization, several processing and quality control problems must be solved to utilize this meat fully.

Just recently, the results of a study on the carbonyl content and taste panel evaluation of mechanically deboned chicken and turkey meat were reported by members of our group (46). Raw and cooked meat samples from deboned broiler necks and backs and turkey racks were analyzed following various storage periods (see Table III). The major monocarbonyls present were alk-2-ones, alkanals, and alk-2-enals. No consistent patterns in the levels of total carbonyls and monocarbonyls were shown to occur during the refrigerated storage of the 2 meat sources. Cooking, however, increased the concentration of these 2 classes of compounds ca. two-fold. The most dramatic change occurred in the level of alk-2-enals in the samples stored for 12 days. The action of heat on lipids during cooking can accelerate autoxidation and thus increase the amount of carbonyl compounds (6). Elevated levels of alkanals also were noted following the extended storage period. Concurrently the panel members could discriminate between the treatment and control samples of deboned broiler meat following 12 days of storage. Lower flavor scores were recorded for deboned turkey meat after just 6 days of refrigerated storage.

We (46) indicated autoxidative deterioration, as shown in Figure 1, was probably responsible for the increase in carbonyl concentrations with storage. However, perhaps the effect of microorganisms may be significant, since in an earlier study (47), we reported the presence of 3 psychrotolerant genera (Pseudomonas, Achromobacter, and Flavobacterium) in similar meat sources held under similar storage conditions.

REFERENCES

1. Doty, D.M., O.F. Batzer, W.A. Landmann and A.T. Santoro, in "Proceedings of the Flavor Chemistry Symposium," Campbell Soup Company, 1961, p. 7-12.
2. Teranishi, R., I. Hornstein, P. Issenberg and E.L. Wick, "Flavor Research," Marcel Dekker, Inc., New York, 1971, p. 1-2.
3. Herz, K.O., and S.S. Chang, Advan. Food Res. 18:2 (1970).
4. Hornstein, I., and P.F. Crowe, J. Agr. Food Chem. 8:494 (1960).
5. Hornstein, I., and P.F. Crowe, Ibid. 11:147 (1963).
6. Thomas, C.P., P.S. Dimick and J.H. MacNeil, Food Tech. 25:109 (1971).
7. Howe, P.E., and N.G. Barbella, Food Res. 2:197 (1937).
8. Sanderson, A., A.M. Pearson and B.S. Schweigert, J. Agr. Food Chem. 14:245 (1966).
9. Hornstein, I., P.F. Crowe and M.J. Heimberg, J. Food Sci. 26:581 (1961).
10. Lea, C.H., Recent Advan. Food Sci. 1:83 (1962).
11. Patton, S., I.J. Barnes and L.E. Evans, JAOCS 36:280 (1959).
12. Huston, C.K., J.D. Sink, R.C. Miller and J.W. Shigley, Ibid. 42:141 (1965).
13. Sink, J.D., and P.W. Smith, J. Food Sci. 37:181 (1972).
14. Hornstein, I., in "Chemistry and Physiology of Flavors," AVI Publishing Co., Westport, Conn., p. 229-250 (1967).
15. Hawke, J.C., J. Dairy Res. 33:225 (1966).
16. Smith, J.L., and J.A. Alford, J. Food Sci. 33:93 (1968).
17. Stringer, W.C., M.E. Bilskie and H.D. Naumann, Food Tech. 23:97 (1969).
18. Bothast, R.J., R.F. Kelly and P.P. Graham, J. Food Sci. 38:75 (1973).
19. Lerche, H., Z. Fleisch-u. Milchhyg. 46:417 (1936).
20. Craig, H.B., A.M. Pearson and N.B. Webb, J. Food Sci. 27:29 (1962).
21. Williams, L.D., A.M. Pearson and N.B. Webb, J. Ani. Sci. 22:166 (1963).
22. Sink, J.D., J. Theoret. Biol. 17:174 (1967).
23. Patterson, R.L.S., J. Sci. Fd. Agric. 19:31 (1968).
24. Beery, K.E., J.D. Sink, S. Patton and J.H. Ziegler, JAOCS 46:439A (1969).
25. Beery, K.E., J.D. Sink, J. Endocr. 51:223 (1971).
26. Beery, K.E., J.D. Sink, S. Patton and J.H. Ziegler, J. Food Sci. 36:1086 (1971).
27. Griffiths, N.M., and R.L.S. Patterson, J. Sci. Food Agric. 21:4 (1970).
28. Gower, D.B., J. Steroid Biochem. 3:45 (1972).
29. Ziegler, J.H., and M.J. Daly, Proc. Recip. Meat Conf. 21:168 (1968).

30. Wasserman, A.E., and F. Talley, J. Food Sci. 33:219 (1968).
31. Batcher, O.M., A.W. Brandt and M.S. Kunze, Ibid. 34:272 (1969).
32. Hofstrand, J., and M. Jacobson, Food Res. 25:706 (1960).
33. Jacobson, M., and H.H. Koehler, J. Agr.. Food Chem. 11:336 (1963).
34. Riley, M.L., J.E. Kunsman, and D.J. Mitchell, Proc. West. Sec. Am. Soc. Ani. Sci. 22:285 (1971).
35. Dimick, P.S., S. Patton, J.E. Kinsella and N.J. Walker, Lipids 1:387 (1966).
36. Watanabe, K., and Y. Sato, Agr. Biol. Chem. 32:1318 (1968).
37. Ziegler, J.H., R.C. Miller, C.M. Stanislaw and J.D. Sink, J. Ani. Sci. 26:58 (1967).
38. Dimick, P.S., N.J. Walker and S. Patton, Biochem. J. 111:395 (1969).
39. Swenson, P.E., and P.S. Dimick, Ibid. 125:1139 (1971).
40. Dimick, P.S., N.J. Walker and S. Patton, J. Agr. Food Chem. 17:649 (1969).
41. Minor, L.J., A.M. Pearson, L.E. Dawson and B.S. Schweigert, J. Food Sci. 30:686 (1965).
42. MacNeil, J.H., and E.G. Buss, Poultry Sci. 47:1566 (1968).
43. Dimick, P.S., and J.H. MacNeil, J. Food Sci. 35:186 (1970).
44. Thomas, C.P., P.S. Dimick and J.H. MacNeil, JAOCS 48:91 (1971).
45. MacNeil, J.H., and P.S. Dimick, J. Food Sci. 35:191 (1970).
46. Dimick, P.S., J.H. MacNeil and L.P. Grunden, Ibid. 37:544 (1972).
47. Ostovar, K., J.H. MacNeil and K. O'Donnel, Ibid. 36:1005 (1971).

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