Peers, F. G. *Biochem. J.* **1953**, *53*, 102.
Pfeffer, E. *Jahrb. Wiss. Bot.* **1872**, *8*, 429.
Pileggi, V. J. *Arch. Biochem. Biophys.* **1959**, *80*, 1.
Pomeranz, Y. *Cereal Chem.* **1973**, *50*, 504.
Posternak, S. *Helv. Chim. Acta* **1921**, *4*, 150.
Rackis, J. J. *J. Am. Oil Chem. Soc.* **1974**, *51*, 161A.
Rackis, J. J.; McGhee, J. E.; Honig, D. H. *J. Am. Oil Chem. Soc.* **1975**, *52*, 249A.
Ranhotra, G. S. *J. Food Sci.* **1972**, *37*, 12.
Ranhotra, G. S. *Cereal Chem.* **1973**, *50*, 353.
Ranhotra, G. S.; Lee, C.; Gelroth, J. A. *Nutr. Rep. Int.* **1978**, *18*, 487.
Ranhotra, G. S.; Loewe, R. J.; Puyat, L. V. *J. Food Sci.* **1974a**, *39*, 1023.
Ranhotra, G. S.; Loewe, R. J.; Puyat, L. V. *Cereal Chem.* **1974b**, *51*, 323.
Rapoport, S.; Leva, E.; Guest, G. M. *J. Biol. Chem.* **1941**, *139*, 621.
Reddy, N. R.; Salunkhe, D. K. *J. Food Sci.* **1981**, *46*, 564.
Reinhold, J. G. *Am. J. Clin. Nutr.* **1971**, *24*, 1204.
Reinhold, J. G. *Ecol. Food Nutr.* **1972**, *1*, 187.
Reinhold, J. G. *J. Am. Diet. Assoc.* **1975**, *66*, 38.
Reinhold, J. G.; Faradji, B.; Abadi, P.; Ismail-Beigi, F. *J. Nutr.* **1976**, *106*, 493.
Reinhold, J. G.; Hedayati, H.; Lahimgarzadeh, A.; Nasr, K. *Ecol. Food Nutr.* **1973a**, *2*, 157.
Reinhold, J. G.; Ismail-Beigi, F.; Faradji, B. *Nutr. Rep. Int.* **1975**, *12*, 75.
Reinhold, J. G.; Nasr, K.; Lahimgarzadeh, A.; Hedayati, H. *Lancet* **1973b**, *1*, 283.
Roberts, A. H.; Yudkin, J. *Nature (London)* **1960**, *185*, 823.
Roberts, R. M.; Loewus, F. *Plant Physiol.* **1968**, *43*, 1710.
Rotruck, J. T.; Luhrsen, K. R. *J. Agric. Food Chem.* **1979**, *27*, 27.
Rowan, K. S.; Turner, D. H. *Aust. J. Biol. Sci.* **1957**, *10*, 414.
Saio, K.; Gallant, D.; Petit, L. *Cereal Chem.* **1977**, *54*, 1171.
Saio, K.; Koyama, E.; Watanabe, T. *Agric. Biol. Chem.* **1967**, *31*, 1195.
Saio, K.; Koyama, E.; Watanabe, T. *Agric. Biol. Chem.* **1968**, *32*, 448.
Samotus, B.; Schwimmer, S. *Nature (London)* **1962**, *194*, 578.
Sathe, U.; Krishnamurthy, K. *Indian J. Med. Res.* **1953**, *41*, 453.
Schormuller, J.; Hohne, R.; Wurdig, G. *Dtsch. Lebensm.-Rundsch.* **1956**, *52*, 213.
Shah, B. G.; Giroux, A.; Belonge, B.; Jones, J. D. *J. Agric. Food Chem.* **1979**, *27*, 387.
Shah, B. G.; Jones, J. D.; McLaughlan, J. M.; Beare-Rogers, J. L. *Nutr. Rep. Int.* **1976**, *15*, 1.
Shieh, T. R.; Ware, J. H. *Appl. Microbiol.* **1968**, *16*, 1348.
Smith, A. K.; Rockis, J. J. *J. Am. Chem. Soc.* **1957**, *79*, 633.
Sobolev, A. M.; Rodionova, M. A. *Sov. Plant Physiol. (Engl. Transl.)* **1966**, *13*, 958.
Steinke, F. H.; Hopkins, D. T. *J. Nutr.* **1978**, *108*, 481.
Suzuki, V.; Yoshimura, K.; Takaishi, M. *Bull. Coll. Agric., Tokyo Imp. Univ.* **1907**, *7*, 503.
Tangkongchitr, U.; Seib, P. A.; Hosney, R. C. *Cereal Chem.* **1981a**, *58*, 226.
Tangkongchitr, U.; Seib, P. A.; Hosney, R. C. *Cereal Chem.* **1981b**, *58*, 229.
Tanner, W. *Ann. N.Y. Acad. Sci.* **1969**, *165*, 726.
Ter-Sarkissian, N.; Azar, M.; Ghavifekr, H.; Ferguson, T.; Hedayat, H. *J. Am. Diet. Assoc.* **1974**, *65*, 651.
Theuer, R. C.; Kemmerer, K. S.; Martin, W. H.; Zoumas, B. L.; Sarett, H. P. *J. Agric. Food Chem.* **1971**, *19*, 555.
Theuer, R. C.; Kemmerer, K. S.; Martin, W. H.; Zoumas, B. L.; Sarett, H. P. *J. Agric. Food Chem.* **1973**, *21*, 482.
Thompson, S. A.; Weber, C. W. *J. Food Sci.* **1979**, *44*, 752.
Toma, R. B.; Tabekhia, M. M. *J. Food Sci.* **1979**, *44*, 619.
Tombs, M. P. *Plant Physiol.* **1967**, *42*, 797.
Tomlinson, R. V.; Ballou, C. E. *Biochemistry* **1962**, *1*, 166.
Uppstrom, B.; Svensson, R. *J. Sci. Food Agric.* **1980**, *31*, 651.
Van Den Berg, C. J.; Hill, L. F.; Stanbury, S. W. *Clin Sci.* **1972**, *43*, 377.
Verma, S. C.; Lal, B. M. *J. Sci. Food Agric.* **1966**, *17*, 43.
Vohra, P.; Gray, G. A.; Kratzer, F. H. *Proc. Soc. Exp. Biol. Med.* **1965**, *120*, 447.
Vohra, P.; Kratzer, F. H. *J. Nutr.* **1966**, *89*, 106.
Wade, H. E.; Morgan, D. M. *Biochem. J.* **1955**, *60*, 264.
Walker, A. R. P. *Lancet* **1951**, *261*, 244.
Walker A. R. P.; Fox, F. W.; Irving, J. T. *Biochem. J.* **1948**, *42*, 452.
Walker, K. A. *Planta* **1974**, *116*, 91.
Wang, H. L.; Swain, E. W.; Hesseltine, C. W. *J. Food Sci.* **1980**, *45*, 1262.
Weingartner, B.; Erdman, J. W.; Parker, H. M.; Forbes, R. M. *Nutr. Rep. Int.* **1979**, *19*, 223.
Weingartner, K. E.; Erdman, J. W. *Ill. Res.* **1978**, *20* (2), 4.
Welch, R. M.; Van Campen, D. R. *J. Nutr.* **1975**, *105*, 253.
Wheeler, E. L.; Ferrel, R. E. *Cereal Chem.* **1971**, *48*, 312.
Williams, S. G. *Plant Physiol.* **1970**, *45*, 376.
Wilson, A. M.; Harris, G. A. *Plant Physiol.* **1966**, *41*, 1416.
Winterstein, E. *Ber. Dtsch. Chem. Ges.* **1879**, *30*, 2299.
Wolf, W. J.; Briggs, D. R. *Arch. Biochem. Biophys.* **1959**, *186*, 85.
Wozenski, J.; Woodburn, M. *Cereal Chem.* **1975**, *52*, 665.
Young, L. *Biochem. J.* **1936**, *30*, 252.

Received for review September 5, 1980. Revised manuscript received July 28, 1981. Accepted September 10, 1981.

Egg and Egg Product Flavor

Joseph A. Maga

The volatiles identified in eggs and egg products are discussed as well as the influence of storage, feed source, and extraneous odors on the flavor properties of eggs.

It has been reported that eggs from a confined bird on a standard commercial ration provides and egg of uniform and bland flavor (Swanson, 1977). On the basis of what is known concerning the basic composition of the egg (Powrie, 1977), one would assume that egg flavor should be fairly well defined at this point. However, surprisingly little is known about the actual composition of this flavor.

In addition, since eggs are reportedly bland, off-flavors can readily become detectable with the resulting organoleptic properties being described by using vague terminologies such as taint, stale, foreign, and flat. Extensive research has been performed in attempting to find means to minimize or eliminate these objectionable flavors, but this approach has been somewhat frustrating, probably due to the fact that the flavor chemistry of the egg and its fractions is far from understood.

Colorado State University, Department of Food Science and Nutrition, Fort Collins, Colorado 80523.

0021-8561/82/1430-0009$01.25/0

Table I. Volatiles Identified in Heated Whole Eggs[a]

hydrocarbons	furans	indans	phenols
n-heptane	2,5-dimethylfuran	indan	*o*-cresol
1-heptene		methylindan	*m*-cresol
n-octane	pyrazines	trimethylindan	*p*-cresol
1-octene	2,6-dimethylpyrazine	*n*-propylindan	
cyclooctane	2-methyl-3-ethylpyrazine	2-(*n*-butyl)indan	sulfides
n-nonane	2,3,5-trimethylpyrazine		dimethyl disulfide
1-nonene	2,6-diethylpyrazine	benzenes	dimethyl trisulfide
n-decane		benzene	
1-decene	pyrroles	ethylbenzene	indoles
1,4-octadiene	pyrrole	*n*-propylbenzene	indole
n-undecane	2,4-dimethylpyrrole	1,3,5-trimethylbenzene	methylindole
1-undecene	ethylmethylpyrrole	*n*-butylbenzene	
n-dodecane		2-butenylbenzene	nitriles
n-tridecane	carbonyls	*n*-pentylbenzene	4-methylpentanenitrile
n-tetradecane	acetaldehyde	*n*-hexylbenzene	styrylnitrile
n-pentadecane	propanal	*n*-heptylbenzene	tolylacetonitrile
5-pentadecene	2-methylpropanal	3-hexenylbenzene	*o*-tolunitrile
n-hexadecane	2-methylbutanal	2-heptenylbenzene	
5-hexadecene	butanone	*n*-octylbenzene	miscellaneous
n-heptadecane		ethylpropylbenzene	toluene
5-heptadecene	alcohols		styrene
5,10-heptadecadiene	1-undecanol		

[a] From MacLeod and Cave (1975, 1976).

Thus, the primary objective of this review is to discuss the few studies that have been directly concerned with egg product flavor as well as present the results of numerous indirect studies. Through this it is hoped that further research will be inspired or intensified, since the egg represents a basic commodity that has found widespread distribution in our diet.

VOLATILES ASSOCIATED WITH WHOLE EGGS

Actually, an egg can serve as an interesting flavor model since all possible reactants in the formation of its characteristic flavor are present in an enclosed system due to the entact shell, and thus, it can be assumed that all of the flavor compounds found in the cooked product were originally present in the raw product or were thermally produced.

MacLeod and Cave (1975, 1976) are some of the few researchers who have investigated the volatiles associated with whole eggs. However, a major problem with both of these studies is that certain basic information is either unclear or missing. For example, regarding their 1975 study, reference is only made to "heated eggs", and since one would assume that the type and amount of heating would significantly alter volatile composition as compared to that of the raw product, their data have no reference point.

Their other publication (MacLeod and Cave, 1976) apparently makes no direct reference as to the state of the eggs utilized. In spite of the above, they did generate numerous informative data relative to the volatile composition of whole eggs. Gas chromatographic analysis revealed the presence of at least 116 compounds of which approximately 65, which represented over 90% of the volatile composition observed, were identified.

With the aid of a stream splitter, an attempt was made to describe the odor properties of the observed peaks. They reported that no peak possessed a typical egg aroma nor could any of the peaks be described as having a pleasant, characteristic egg aroma. Thus, they concluded that the relatively bland flavor associated with normal eggs is not due to a specific small number of volatile compounds.

As can be seen in Table I, numerous compound classes were identified. For example, all the straight-chain hydrocarbons from C_7 to C_{17} were found, with *n*-pentadecane being the major compound of this series. Likewise, a series of unsaturated straight-chain hydrocarbons ranging from 1-heptene to 1-undecene was present. Three longer chain unsaturated straight-chain hydrocarbons, with the double bond in the 5 position, were also identified, with 5-heptadecene being the most prevalent of all volatiles. The authors postulated that hydrocarbons could result from the decarboxylation of fatty acids from glycerides. Straight-chain alkyl- and alkenylbenzenes, which could have originated from the thermal degradation of glucose, carotenoids, or amino acids, all of which are present in egg, were also found. Other identified compounds included three simple phenols and a series of indans. In fact, indan (2,3-dihydroindene) was the second most abundant volatile. Other minor classes of compounds found included indoles, pyrroles, pyrazines, and sulfides. Apparently, their methodology did not permit the identification of hydrogen sulfide, which was originally identified in heated eggs by Tinkler and Soar (1920). Germs (1973) has demonstrated that hydrogen sulfide in eggs results from a nonenzymic reaction from the protein fraction and that its formation is pH dependent. In addition to hydrogen sulfide, Germs (1973) identified lanthionine and ammonia in heated eggs.

In their later study, MacLeod and Cave (1976) reported on the relative percentage abundance of various volatiles as influenced by the variables of battery (cages) vs. free range (open field) eggs, white- vs. brown-shelled eggs, eggs of different ages, and between egg yolk and whole egg. For some unexplained reason, egg whites were not evaluated. By comparing total normalized gas chromatographic peak areas, the authors reported that volatile concentration increased with storage. After 1 week of storage at 12 °C, total volatiles increased 4-fold over a fresh (several hours old) control. Three weeks of storage at 12 °C resulted in a 5-fold increase in total volatiles. Specific compounds classes that changed most in relative concentration with storage included increases of carbonyls, aliphatic hydrocarbons, nitriles, and indans with decreases in alkylbenzenes and indoles. An early sensory study on stored egg flavor by McCammon et al. (1934) also demonstrated that flavor intensified with storage time. When comparison of the volatiles from eggs produced under battery conditions as compared to free range production was evaluated, it was found that free range eggs had higher levels of sulfur and pyrazine compounds but lower levels

of alkylbenzenes. However, an unspecified number of untrained personnel, using the sensory triangle test, could not significantly establish a sensory difference between the two types of eggs. No significant volatile and sensory differences were detected when brown-shelled eggs were compared to white-shelled eggs. Although two varieties of chickens were used, both consumed the same feed source, thus minimizing any possible differences.

Recently, Gil and MacLeod (1981) expanded upon the identification of several compounds that were tentatively identified in previous work (MacLeod and Cave, 1975). Through synthesis and comparison of gas chromatographic mass spectrometric data, they concluded that 2-butylindan and 1,2,4-trithiolane were definitely present in heated eggs, but *O*-decylhydroxylamine was not. The sensory properties of the two positive compounds were discussed with 1,2,4-trithiolane having an intense garlic odor and 2-butylindan possessing a sweet, fruity, oily property. Thus, neither compound was thought to contribute significantly to egg aroma.

Rayner et al. (1980) have proposed a modified gas chromatographic procedure for the objective evaluation of egg odor quality. Pasteurized whole eggs that had been stored for varying amounts of time at different temperatures were evaluated by the technique. Eggs that had previously been organoleptically judged to be satisfactory provided a chromatographic pattern of low-intensity peaks, whereas other eggs judged to be "sour" had dramatically different chromatographic profiles. In spite of the fact that only five compounds were identified including ethanol, methylpropanal, diacetyl, 3-methylbutanal, and 3-hydroxy-2-butanone, the authors presented nonquantitative data demonstrating that "sour" aroma was associated with increases in all five identified volatiles, with many-fold increases in ethanol and 3-hydroxy-2-butanone. The authors suggested that refinement of the technique could result in its use to monitor these apparent decomposition products relative to egg product shelf life. It would be of interest to perform this type of analysis on raw eggs to see if the objective test follows subjective organoleptic evaluation with nonheated eggs. It would also be of interest to evaluate the above technique on various egg fractions in an effort to pinpoint which fraction is most prone to the observed overall change in volatiles.

Thus, although a wide variety of compounds has been identified in whole eggs, to date no definitive answer as to what is egg flavor has been obtained. Perhaps future application for synthetic egg flavor will spur further investigations in this area. It would also be of value to quantitate the individual volatile compounds identified in egg relative to their individual odor thresholds in an effort to provide clues as to which compounds or classes of compounds indirectly significantly contribute to egg flavor. Lastly, the flavor chemist should not dismiss the potential role of the contribution of nonvolatiles to the overall sensory properties of the egg.

YOLK VOLATILES

One could rationalize that it would perhaps be easier to understand the chemistry of egg flavor by first looking at the flavor properties of the yolk and white portions separately. Several studies have appeared utilizing this approach. For example, MacLeod and Cave (1976) compared the total volatiles from the yolk with the volatiles produced by the entire egg and found that the yolk produced fewer ketones and indoles but more pyrazines, thus indirectly demonstrating the role of the egg white in total egg flavor. A major difference between yolk and whole egg was the fact that in the whole egg 2-methylbutanal only represented 0.6% of the total volatiles whereas in the yolk it represented 28% of the volatiles. Amino acid compositional differences between egg white and yolk were thought to be the major reason for this difference.

Koehler and Jacobson (1966) conducted an extensive sensory evaluation, which included both flavor profile analysis and intensity ratings, of the aroma, taste, and aftertaste of cooked fresh whole egg, fresh unfractionated yolk, and yolk fractions that had been separated by ultracentrifugation. They reported that both the characteristics noted and their order of perception varied among the three products. The terms richness, mustiness, and astringency were more intense in the whole yolk and fractionated yolk as compared to the whole egg, thus indicating that these flavors were primarily derived from the yolk instead of the white portion. In addition, a "hydrolyzed protein" aroma and taste were evident in whole egg and certain yolk fractions but not in unfractionated yolk.

The odor and flavor properties of raw and cooked egg yolks as influenced by protein source in the chicken diet were subjectively evaluated by Colas et al. (1979). A standard diet containing soybean meal was substituted with either 30% field peas, 15% field beans, 10% fish meal, 6% lucerne meal, 10% meat and bone meal, or 11.5% spiruline algae. None of the diets resulted in major changes in the aroma and flavor of raw yolks. However, when cooked the fish meal, lucerne meal and algae diets produced inferior yolks, while field beans and meat and bone meal diets resulted in no difference, and field peas produced a superior egg yolk. Thus, the above study clearly demonstrates that diet can significantly influence the organoleptic properties of egg yolk and, in turn, the overall properties of the whole egg.

Egg White Volatiles. Since the egg white is the major weight portion of the egg (Powrie, 1977), several researchers have been primarily interested in the flavor properties associated with this fraction. For example, Frampton and Romanoff (1945) reported that ammonia was associated with egg whites. Weurman and de Rooij (1961) reportedly found no amines associated with the egg white portion of fresh eggs but did find methyl-, dimethyl-, ethyl-, and trimethylamine in whole eggs, thus indicating that amines are derived from the yolk portion of egg. Sato et al. (1968) identified a series of six common carbonyl compounds, along with four volatiles in the basic fraction (ammonia, methyl- and dimethylamine, and putresine) of egg whites. They also attempted to quantitate any differences in the amount of volatiles as influenced by summer or winter egg harvest, but no significant differences were found.

The volatile basic compounds associated with both egg whites and ovalbumin, the major protein of egg white, after the products had been heated at 120 °C for 2 h at pH 10 were reported by Kato et al. (1978). A total of 11 compounds were identified including pyridine and 2-methylpyridine, pyrazine and six alkyl-substituted pyrazines, and two alkyl-substituted thiazoles. Pyridine levels were significantly higher in the ovalbumin fraction as compared to those in the egg white. In contrast, the egg white was higher in pyrazines. Dimethylthiazole levels were approximately the same in both products, but trimethylthiazole in the ovalbumin was twice as high as that in egg white. Baker et al. (1967) reported that albumin served as the source of hydrogen sulfide formation in eggs.

In the study attributed to Colas et al. (1979) as described in the yolk section, the sensory quality of both raw and cooked whites was also investigated as influenced by

Table II. Volatiles Identified in Fermented Eggs[a]

fatty acids	alcohols	esters	propyl valerate	miscellaneous
formic acid	methanol	methyl acetate	butyl isobutyrate	dimethyl disulfide
acetic acid	ethanol	ethyl acetate	ethyl isocaproate	toluene
propionic acid	1-propanol	methyl propionate	butyl butyrate	*o*-xylene
isobutyric acid	2-mercaptoethanol	propyl formate	ethyl caproate	*m*-xylene
butyric acid	isoamyl alcohol	methyl isobutyrate	methyl heptanoate	*p*-xylene
isovaleric acid		ethyl propionate	butyl isovalerate	α-pinene
valeric acid	carbonyls	propyl acetate	amyl butyrate	*p*-cymene
isocaproic acid	acetaldehyde	methyl butyrate	propyl isocaproate	limonene
caproic acid	acetone	ethyl isobutyrate	isoamyl butyrate	acetophenone
heptanoic acid	propanal	isobutyl acetate	isobutyl valerate	
caprylic acid	2-pentanone	methyl isovalerate	propyl caproate	
nonanoic acid	pentanal	ethyl butyrate	ethyl heptanoate	
capric acid	2-hexanone	propyl propionate	methyl caprylate	
	2-heptanone	butyl acetate	isobutyl caproate	
amines	octanal	isopropyl butyrate	butyl isocaproate	
trimethylamine		methyl valerate	butyl caproate	
isobutylamine	benzenes	ethyl isovalerate	propyl heptanoate	
butylamine	benzene	propyl isobutyrate	ethyl caprylate	
isoamylamine	ethyl benzene	isoamyl acetate	amyl caproate	
amylamine	1,3,5-trimethylbenzene	propyl butyrate	isobutyl heptanoate	
hexylamine	1,2,4-trimethylbenzene	ethyl valerate	isoamyl caproate	
heptylamine	1,2,3-trimethylbenzene	butyl propionate	butyl heptanoate	
octylamine		isobutyl butyrate	propyl caprylate	
β-phenylethylamine		methyl caproate	ethyl nonanoate	

[a] From Bullard et al. (1978a).

protein source in the diet. They reported that both raw and cooked egg whites were significantly influenced by diet. In light of the fact that diet did not significantly influence the sensory properties of raw yolks, it would appear that whites are the major contributor to overall egg flavor in both the raw and cooked states.

On the basis of the composition of the basic volatile fraction isolated from egg whites by Kato et al. (1978), which predominated in pyrazines and thiazoles, it is suggested by this author that heterocyclic nitrogen-containing compounds may play a major role in heated egg flavor. Compounds of this type have a wide distribution and significant flavor contribution in numerous foods and undoubtedly represent the most promising contributors to egg flavor. Specific analysis for the above classes of compounds in egg, especially the white portion, should reveal numerous other such compounds whose potent sensory properties should prove to play a major role in characteristic egg flavor.

Fermented Egg Volatiles. Normally fermented eggs are not consumed by humans, but the unique organoleptic properties of this product has lead to its application as an animal and insect attractant and/or repellent. For example, Hwang and Mulla (1971) reported that certain compounds in fermented chicken whole egg powder attracted eye gnats. Later studies (Hwang and Mulla, 1973; Hwang et al., 1975, 1976a,b) concluded that trimethylamine and ammonia formed during fermentation were the primary compounds responsible for this earlier observation.

The volatiles from fermented eggs have been shown to attract coyote (Linhart and Knowlton, 1975). However, in the case of deer, the product is reported to be a repellent (Dodge et al., 1967). Recently Bullard et al. (1978a) quantitated the presence of 13 volatile fatty acids and 8 amines as well as identify 76 other volatile compounds associated with fermented whole eggs. This interesting array of compounds is summarized in Table II. They concluded that the overall aroma of the product was composed of four characteristic notes described as cheesy from volatile fatty acids, ammoniacal from amines, fruity from esters, and sulfurous from organosulfur compounds. Based on their earlier work (Bullard et al., 1978a), Bullard et al. (1978b) synthesized an effective attractant/repellent utilizing the volatiles associated with fermented eggs. As expected, the intensity of volatiles present influenced the effectiveness of the synthetic mixture.

The presence of various volatile acids has also been suggested as a means to monitor egg decomposition. These include isovaleric acid (Bethea and Wong, 1968), lactic and succinic acids (Salwin and Bond, 1969), β-hydroxybutyric acid (Staruszkiewicz et al., 1970; Staruszkiewicz and Starling, 1971), and acetic and lactic acids (Reagan et al., 1971).

Dehydrated Egg Product Flavor. The flavor properties of dehydrated eggs, especially with storage, is an area that has experienced much research and patent attention. Much research has been conducted on egg pretreatment before dehydration to minimize oxidative flavor deterioration, and numerous analytical procedures have been suggested to follow these chemical changes (Privett et al., 1964; Tuomy and Walker, 1970; Lorenz and Maga, 1971). Glucose is thought to be the main flavor-associated problem in dehydrated eggs (Bergquist, 1977).

Comparison of the volatiles associated with fresh and dried eggs by MacLeod and Cave (1976) demonstrated that dried eggs had lower levels of alkylbenzenes and higher levels of pyrazines. The authors also reported that enzyme reactions are probably not important in the development of typical egg flavor since dried eggs and cooked eggs has similar volatile profiles, thus indicating that thermally induced flavor formation was predominant.

Feed Associated Flavors. Traditionally, feed and feed additives have been thought to be a problem source relative to egg flavor. It is generally believed that strongly flavored feeds can impart their flavor to eggs and that egg yolks easily absorb both flavors and odors (McCammon et al., 1934). Different feed rations (McCammon et al., 1934) were shown to influence both odor and flavor of egg yolks but odor to a more adverse level. Vondell (1948) reported that an off-flavor described as "fishy eggs" was first thought to be caused by the inclusion of fish meal in diets, but it was demonstrated that not all breeds or chickens within a breed produce eggs with this off-flavor. He reported that approximately 3% of the flock of a susceptible breed was prone to this defect and that the defect was most prevalent in the fall and winter. In addition, chickens that produced "fishy eggs" were noted to have a peculiar breath resembling old silage. Culling of bad breath chickens was

suggested as a means of controlling this off-flavor.

Confusing data exist as to the influence of dietary fat source on resulting egg flavor. For example, tallow fed at a level of 3% did not change the flavor of fresh or stored eggs (Carver et al., 1955) but higher levels apparently did (Jordan et al., 1960). Conflicting data also exist for the influence of fish oil in the diet. Vondell and Putnam (1945) reported that the addition of sardine oil did not influence egg flavor quality. However, Holdas and May (1966) concluded from their data that menhaden fish oil did significantly alter egg flavor. Koehler and Bearse (1975) evaluated various levels of several fish meals and oils in chicken rations which they related to egg flavor. Overall they reported that the longer the diets were consumed, the poorer the resulting egg flavor quality. Diets containing hake meal and Canadian Atlantic herring meal resulted in lower flavor quality eggs than the use of British Columbia herring meal. Peruvian anchovy oil at a level of 1.5% produced off-flavored eggs.

The "fish egg" aroma compound was identified by Hobson-Frohock et al. (1973) to be trimethylamine. Analysis of off-flavored eggs revealed levels of trimethylamine greater than 10 times the amounts found in normal eggs. They also verified that it was species related since it only occurred in brown-shelled eggs. It was also suggested that certain batches of rapeseed meal used in the diet could contain the trimethylamine precursor. The role of rapeseed meal was further evaluated (Hobson-Frohock et al., 1975, 1977; Fenwick et al., 1979), and it was then believed that sinapine in the product was responsible for the off-flavor development in eggs. Recently, the sensory properties of trimethylamine in eggs were further defined by Griffiths et al. (1979), and a quantitative procedure for eggs was reported (Hobson-Frohock, 1979).

Recently Wakeling et al. (1980) demonstrated that a "fishy" taint in eggs was associated with feeding Icelandic herring. Then 2.5–7% of the resulting eggs smelled "fishy" and 17% had a "crabby" taint. Analysis of these eggs resulted in trimethylamine levels ranging from 9 to 17 $\mu g/g$ which is significantly higher than the odor threshold of 0.8 $\mu g/g$ for the compound. Thus, it would appear that poultry feed manufacturers should routinely check incoming feed ingredients for their trimethylamine levels in order to minimize potential feed-associated off-flavors in eggs.

Choline and/or a metabolite of choline has now been implicated in the production of trimethylamine in eggs (March and MacMillan, 1979) due to the microbial formation of trimethylamine from choline. They found measurable levels of trimethylamine in the caeca and small intestine of chickens that increased significantly when rapeseed meal or supplementary choline was added to the diet. Apparently a genetic deficiency among certain breeds does not permit the liver to oxidize trimethylamine and thus it is deposited in the egg. Leeson and Summers (1978) have reported that rapeseed and soybean gums, both of which contain high levels of choline in the form of phosphatidalcholine, can produce this flavor defect and thus degummed meals should be used in chicken diets.

Angalet et al. (1976) substituted up to 10% of citrus sludge in diets and reported no significant flavor differences in the resulting eggs.

Contaminated wood shavings used for bedding or contaminated feed was thought to be the sources of off-flavored eggs that were found to contain tetrachloroanisole and trichlorzanisole along with tri- and tetrachlorophenol (Bemelmans and ten Noever de Brauw, 1974). Earlier researchers had found similar results (Engel et al., 1966; Curtis et al., 1972).

Absorption of Extraneous Odors. Off-flavors in eggs due to the absorption of extraneous odors has also been evaluated. The most extensive study in this area was performed by Kato et al. (1971). They determined absorption rates through the egg shell of single compounds representing various classes of volatile compounds. It was found that aldehydes were more easily absorbed into eggs than ketones, esters, or alcohols. Also, the rates of absorption and dispersion were found to be inversely proportional to the number of carbon atoms and independent of molecular weights or boiling points. MacLeod and Cave (1977) investigated the extent of ethyl propyl sulfide absorption into eggs as influenced by the age of the eggs and by exposure time. They found that the age of the egg before exposure had no influence on the amount of the compound absorbed but, as expected, the length of the exposure did have an important influence. For some unexplained reason, minimum exposure time was 18 h under refrigerated conditions which resulted in approximately 10% of the volatiles being sulfide. When exposure time was increased to 48 h, sulfide represented approximately 20% of the volatiles, and after 168 h of exposure, sulfide concentration was 29% in the egg interior.

Influence of Storage Conditions. The development of a stale flavor during the storage of eggs has prompted much investigation into means of retarding this flavor change. Most of this work was done years ago and little recent literature is available. Eggs that have their shells coated with mineral oils were found to be more resistant to absorption of extraneous odors from the environment (Harns et al., 1954), but the treatment did not retard the development of internally associated stale flavor (Banwart et al., 1957). Also, oiling eggs before storage was found to retard losses of moisture and carbon dioxide (Banwart et al., 1957). Modification of atmosphere relative to whole egg flavor stability was investigated by Fletcher et al. (1959). They found that vacuum packaging did not significantly result in a better flavored egg with storage and that packaging in carbon dioxide decreased egg flavor and odor scores. A similar type study was conducted by Hard et al. (1963) involving five preservation methods at three temperatures during three seasons of the year. At 32 and 55 °F untreated eggs were found to be the most acceptable from a flavor standpoint. At 72 °F a silicone grease treatment was found to be most effective in maintaining typical egg flavor. No stale flavor differences were noted when summer-, fall-, and spring-produced eggs were compared. It should be noted that some researchers (Stadelman, 1977) feel that oil dipping eggs is overall harmful to egg flavor since the oil can prevent the loss of off-flavors from within the egg.

CONCLUSIONS

Although various aspects of egg flavor chemistry have been investigated, to date the specific compounds contributing to characteristic egg flavor are not known. In addition, most of the objectionable flavors associated with eggs have been traced to various feed sources.

LITERATURE CITED

Angalet, S. A.; Fry, J. L.; Damron, B. L.; Harms, R. H. *Poult. Sci.* **1976**, *55*, 1219.
Baker, R. C.; Darfler, J.; Lifshitz, A. *Poult. Sci.* **1967**, *46*, 664.
Banwart, S. F.; Carlin, A. F.; Cotterill, O. J. *Food Technol. (Chicago)* **1957**, *11*, 200.
Bemelmans, J. M. H.; ten Noever de Brauw, M. C. *J. Agric. Food Chem.* **1974**, *22*, 1137.
Bergquist, D. H. "Egg Science and Technology", 2nd ed.; AVI: Westport, CT, 1977; Chapter 14.
Bethea, S.; Wong, N. P. *J. Assoc. Off. Anal. Chem.* **1968**, *51*, 1216.

Bullard, R. W.; Leiker, T. J.; Peterson, J. E.; Kilburn, S. R. *J. Agric. Food Chem.* **1978a**, *26*, 155.
Bullard, R. W.; Shumake, S. A.; Campbell, D. L.; Turkowski, F. J. *J. Agric. Food Chem.* **1978b**, *26*, 160.
Carver, D. S.; Rice, E. E.; Gray, R. E.; Mone, P. E. *Poult. Sci.* **1955**, *34*, 131.
Colas, B.; Sauvageot, F.; Harscoat, J. P.; Sauveur, B. *Ann. Zootech.* **1979**, *28*, 297.
Curtis, R. F.; Land, D. G.; Griffiths, N. M.; Gee, M.; Robinson, D.; Peel, J. L.; Dennis, C.; Gee, J. M. *Nature (London)* **1972**, *235*, 223.
Dodge, W. E.; Loveless, C. M.; Kverno, N. B. *For. Sci.* **1967**, *13*, 333.
Engel, C.; de Groot, A. P.; Weurman, C. *Science (Washington, D.C.)* **1966**, *154*, 270.
Fenwick, G. R.; Hobson-Frohock, A.; Land, D. G.; Curtis, R. F. *Br. Poult. Sci.* **1979**, *20*, 323.
Fletcher, D. A.; Orr, H. L.; Snyder, E. S.; Nicholson, A. O. *Poult. Sci.* **1959**, *38*, 106.
Frampton, V. L.; Romanoff, A. L. *Arch. Biochem.* **1945**, *13*, 315.
Germs, A. C. *J. Sci. Agric.* **1973**, *24*, 7.
Gil, V.; MacLeod, A. J. *J. Agric. Food Chem.* **1981**, *29*, 484.
Griffiths, N. M.; Land, D. G.; Hobson-Frohock, A. *Br. Poult. Sci.* **1979**, *20*, 555.
Hard, M. H.; Spencer, J. V.; Locke, R. S.; George, M. H. *Poult. Sci.* **1963**, *42*, 815.
Harns, J. V.; Sauter, E. A.; McLaren, B. A.; Stadelman, W. J. *Poult. Sci.* **1954**, *34*, 992.
Hobson-Frohock, A. *J. Food Technol.* **1979**, *14*, 441.
Hobson-Frohock, A.; Fenwick, G. R.; Heaney, R. K.; Land, D. G.; Curtis, R. F. *Br. Poult. Sci.* **1977**, *18*, 529.
Hobson-Frohock, A.; Fenwick, G. R.; Land, D. G.; Curtis, R. F.; Gulliver, A. L. *Br. Poult. Sci.* **1975**, *16*, 219.
Hobson-Frohock, A.; Land, D. G.; Griffiths, H. M.; Curtis, R. F. *Nature (London)* **1973**, *243*, 304.
Holdas, A.; May, K. N. *Poult. Sci.* **1966**, *45*, 1405.
Hwang, Y. S.; Mulla, M. S. *Ann. Entomol. Soc. Am.* **1971**, *64*, 1086.
Hwang, Y. S.; Mulla, M. S. *J. Econ. Entomol.* **1973**, *66*, 1339.
Hwang, Y. S.; Mulla, M. S.; Axelrod, H. *Environ. Entomol.* **1975**, *4*, 769.
Hwang, Y. S.; Mulla, M. S.; Axelrod, H. *J. Agric. Food Chem.* **1976a**, *24*, 164.
Hwang, Y. S.; Mulla, M. S.; Axelrod, H. *Environ. Entomol.* **1976b**, *5*, 65.
Jordan, R.; Vail, G. E.; Rogler, J. C.; Stadeuman, W. J. *Food Technol. (Chicago)* **1960**, *14*, 418.
Kato, Y.; Watanabe, K.; Sato, Y. *Nippon Nogei Kagaku Kaishi* **1971**, *45*, 386.
Kato, Y.; Watanabe, K.; Sato, Y. *Lebensm.-Wiss. Technol.* **1978**, *11*, 128.
Koehler, H. H.; Bearse, G. E. *Poult. Sci.* **1975**, *54*, 881.
Koehler, H. H.; Jacobson, M. *Poult. Sci.* **1966**, *45*, 1371.
Leeson, S.; Summers, J. D. *Poult. Sci.* **1978**, *57*, 314.
Linhart, S. B.; Knowlton, F. F. *Wildl. Soc. Bull.* **1975**, *3*, 114.
Lorenz, K.; Maga, J. A. *J. Food Sci.* **1971**, *36*, 936.
MacLeod, A. J.; Cave, S. J. *J. Sci. Food Agric.* **1975**, *26*, 351.
MacLeod, A. J.; Cave, S. J. *J. Sci. Food Agric.* **1976**, *27*, 799.
MacLeod, A. J.; Cave, S. J. *J. Food Sci.* **1977**, *42*, 539.
March, B. E.; MacMillan, C. *Poult. Sci.* **1979**, *58*, 93.
McCammon, R. B.; Pittman, M. S.; Wilhelm, L. A. *Poult. Sci.* **1934**, *13*, 95.
Powrie, W. D. "Egg Science and Technology", 2nd ed.; AVI: Westport, CT, 1977; Chapter 6.
Privett, O. S.; Romanus, O.; Kline, L. *Food Technol. (Chicago)* **1964**, *18*, 1485.
Rayner, E. T.; Dupuy, H. P.; Legendre, M. G.; Schuller, W. H. *Poult. Sci.* **1980**, *59*, 2348.
Reagan, J. G.; York, L. R.; Dawson, L. E. *J. Food Sci.* **1971**, *36*, 351.
Salwin, H.; Bond, J. F. *J. Assoc. Off. Anal. Chem.* **1969**, *52*, 41.
Sato, Y.; Watanabe, K.; Tanaka, Y. *Agric. Biol. Chem.* **1968**, *32*, 405.
Stadelman, W. J. "Egg Science and Technology", 2nd ed.; Avi: Westport, CT, 1977; Chapter 4.
Staruszkiewicz, W. F.; Bond, J. F.; Salwin, H. *J. Chromatogr.* **1970**, *51*, 423.
Staruszkiewicz, W. F.; Starling, M. K. *J. Assoc. Off. Anal. Chem.* **1971**, *54*, 773.
Swanson, M. H. "Egg Science and Technology", 2nd ed.; AVI: Westport, CT, 1977; Chapter 2.
Tinkler, C. K.; Soar, M. C. *Biochem. J.* **1920**, *14*, 144.
Tuomy, J. M.; Walker, G. C. *Food Technol. (Chicago)* **1970**, *24*, 1287.
Vondell, J. H. *Poult. Sci.* **1948**, *27*, 244.
Vondell, J. H.; Putnam, J. N. *Poult. Sci.* **1945**, *24*, 284.
Wakeling, D. E.; Fenwick, G. R.; Pearson, A. W.; Butler, E. J. *Vet. Rec.* **1980**, *107*, 431.
Weurman, C.; de Rooij, C. *J. Food Sci.* **1961**, *26*, 239.

Received for review July 22, 1980. Revised manuscript received July 28, 1981. Accepted September 4, 1981.

Recent Developments in Corn Protein Research

Jerrold W. Paulis

Corn grain consists predominantly of zein and other alcohol-soluble components that are deficient in lysine. Protein of high-lysine corns such as *opaque*-2 and *floury*-2 contains a smaller proportion of these alcohol-soluble proteins. Recent studies were carried out by our laboratory of the structure of zein and its genetic variations as means to identify various races and ancestral lines of corns. An alcohol-soluble fraction was isolated from the reduced glutelin and shown to be distinct from zein by amino acid analysis and electrophoresis. The increase in this lysine-deficient but methionine-rich alcohol-soluble glutelin fraction in su_1 lines enhances the methionine content of the grain—a desirable characteristic in feed formulations.

Corn is a principal source of food for millions of people, particularly in Latin America and Africa. It is an excellent source of carbohydrates, but its protein quality is relatively poor because it is deficient in the essential amino acids lysine and tryptophan. Mertz et al. (1964) showed that the endosperm of corn seeds homozygous for the *opaque*-2 (o_2) mutant gene had a higher lysine content than normal endosperm. Mutation at the o_2 locus dramatically alters the relative amounts of the different endosperm proteins, which vary in amino acid compositions. This finding that introduction of the o_2 mutant gene into corn improved the

Northern Regional Research Center, Agricultural Research, Science and Education Administration, U.S. Department of Agriculture, Peoria, Illinois 61604.