- Jurenitsch, J.; David, M.; Hersch, F.; Kubelka, W. Planta Med. 1979b, 36, 61.
- Kosma-Kovacs, E.; Kevie-Pichler, E.; Lendvai, E. Acta Aliment. Acad. Sci. Hung. 1977, 6, 1.
- Lee, K. R.; Suzuki, T.; Kobashi, M.; Hasegawa, K.; Iwai, K. J. Chromatogr. 1976, 123, 119.
- Masada, Y.; Hashimoto, K.; Inoue, T.; Suzuki, M. J. Food Sci. 1971, 36, 858.
- Palacio, J. J. R. J. Assoc. Off. Anal. Chem. 1977, 60, 970.
- Pankar, D. S.; Magar, N. G. J. Chromatogr. 1977, 144, 149.
- Pankar, D. S.; Magar, N. G. J. MAU 1978, 3, 116.
- Polesello, A.; Pizzocaro, F. Riv. Sci. Technol. Alim. Nutr. Um. 1976, 6, 25.
- Rajpoot, N. C.; Govindarajan, V. S. J. Assoc. Off. Anal. Chem. 1981, 64, 311.
- Sandler, S. R.; Karo, W., Eds. "Organic Functional Group Preparations"; Academic Press: New York, 1968a; p 222.
- Sandler, S. R.; Karo, W., Eds. "Organic Functional Group Preparations"; Academic Press: New York, 1968b; p 224.

Sankarikutty, B. J. Food. Sci. Technol. 1978, 15, 126.

- Sticher, O.; Soldati, F.; Joshi, R. K. J. Chromatogr. 1978, 166, 221.
- Suzuki, T.; Kawada, T.; Iwai, K. J. Chromatogr. 1980, 198, 217.
- Technical Information Bulletin "Vitride Reducing Agent"; Realco Chemical Co.: New Brunswick, NJ, 1974; p 6.
- Tirimanna, A. S. L. Analyst (London) 1972, 97, 372.
- Todd, P., Jr.; Bensinger, M.; Biftu, T. J. Chromatogr. Sci. 1975, 13, 577.
- Todd, P. H.; Bensinger, M. G.; Biftu, T. J. Food Sci. 1977, 42, 660.
- Todd, P. H., Jr.; Perun, C. Food Technol. (Chicago) 1961, 15, 270.
- Wiley, G. A.; Hershkowitz, R. L.; Rein, B. M.; Chung, B. C. J. Am. Chem. Soc. 1964, 86, 964.

Woodbury, J. E. J. Assoc. Off. Anal. Chem. 1980, 63, 556.

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# Vitamin E Content of Feedstuffs Determined by High-Performance Liquid Chromatographic Fluorescence

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A method is described for the extraction and high-performance liquid chromatographic separation and quantitation of naturally occurring tocopherols and tocotrienols in feedstuffs. Validation of the method in feedstuffs is also reported including reproducibility, linearity, recovery, and precision. A survey of U.S. feedstuffs was performed by using this developed method, and the results are presented showing the  $\alpha$ -,  $\beta$ -,  $\gamma$ -, and  $\delta$ -tocopherols and the  $\alpha$ - and  $\gamma$ -tocotrienols of animal feedstuffs collected in five major areas of the United States. Assay results from 77 samples are included.

There are eight naturally occurring forms of vitamin E:  $\alpha$ -,  $\beta$ -,  $\gamma$ -, and  $\delta$ -tocopherol and  $\alpha$ -,  $\beta$ -,  $\gamma$ -, and  $\delta$ -tocotrienol. Various analytical techniques have been used to detect, separate, and quantitate these compounds. Bunnell et al. (1968) reported a comprehensive survey of the  $\alpha$ -tocopherol content of feedstuffs in which gas-liquid chromatography was used for the determination of  $\alpha$ -tocopherol in alfalfa and secondary magnesium phosphate chromatography followed by two-dimensional thin-layer chromatography used for the separation and determination of  $\alpha$ -tocopherol and  $\alpha$ -tocotrienol. Bieri et al. (1970) and Ames (1971) reported the use of colorimetric methods to determine  $\alpha$ -tocopherol and total tocopherols. Other significant contributors to vitamin E analytical methodology include Lovelady (1973), Tangney et al. (1978), and Slover (1971). Bunnell (1971) provides a thorough review of the development of analytical procedures for vitamin E.

The advent of high-performance liquid chromatography (HPLC) as an accepted technique for vitamin analysis has provided the analytical chemist with methods that offer advantages in speed, accuracy, and specificity over those available in the past. Abe et al. (1975), Vatassery et al. (1978), and Carpenter (1979) have reported the HPLC separation of  $\alpha$ -,  $\beta$ -,  $\gamma$ -, and  $\delta$ -tocopherol. Thompson and Hatina (1979) used HPLC to separate and determine the four tocopherols and  $\alpha$ -,  $\beta$ -, and  $\gamma$ -tocotrienol in a variety

of tissues and foods. Manz and Philipp (1981) reported a method for the determination of  $\alpha$ -tocopherol and  $\alpha$ tocotrienol in animal feeds and human foodstuffs. Other applications of HPLC in vitamin E analysis include the work of Eriksen (1980), Cohen and Lapointe (1980), and Widicus and Kirk (1979).

The purpose of this investigation was to determine the tocopherol and tocotrienol contents of a wide variety of feedstuffs by using HPLC. The separation and identification of all eight vitamin E isomers were achieved. However, the quantitation of  $\beta$ - and  $\delta$ -tocotrienol was not reported due to the instability and insufficient purity of available standards. The procedure has proved itself to be reliable and suitable for routine laboratory use including the determination of the  $\alpha$ -tocopheryl acetate content of mixed feeds.

### MATERIALS AND METHODS

High-Performance Liquid Chromatography. The HPLC system used consisted of a Model 950 HPLC pump (Tracor Inc.), a Model 650-10 LC fluorescence detector (Perkin Elmer Corp.) with excitation at  $294 \pm 2$  nm and emission at  $325 \pm 2$  nm, a Model 7120 injector (Rheodyne) equipped with a 20- $\mu$ L loop, and a normal-phase Chromegasphere SI 60, 5  $\mu$ m, column, 15 cm × 4.6 mm i.d. (E. S. Industries). Chromatograms were recorded and peak areas determined by using a Model 3390 integrator (Hewlett-Packard). The mobile phase was 2.5% (v/v) tetrahydrofuran in isooctane with a flow rate of 1.5 mL/ min. The injection volume was 20  $\mu$ L. All solvents used

Hoffmann-La Roche, Inc., Product Development & Applications, Nutley, New Jersey 07110.



**Figure 1.** Chromatogram of standard solutions:  $\alpha$ -tocopherol, 0.60 µg/mL;  $\alpha$ -tocotrienol, 0.68 µg/mL;  $\beta$ -tocopherol, 0.76 µg/mL;  $\beta$ -tocotrienol, 1.31 µg/mL;  $\gamma$ -tocopherol, 1.70 µg/mL;  $\gamma$ -tocotrienol, 1.20 µg/mL;  $\delta$ -tocopherol, 1.69 µg/mL;  $\delta$ -tocotrienol, 1.48 µg/mL.

were chromatographic grade (Burdick and Jackson). The ascorbic acid used was USP-FCC. All other reagents used were reagent grade.

**Standards.** The following standards were used:  $\alpha$ -tocopherol in sealed ampules (Eastman Organic Chemicals);  $\beta$ -tocopherol, isolated and purified from wheat germ oil (Sigma Chemical Co.);  $\gamma$ - and  $\delta$ -tocopherol, and  $\alpha$ -,  $\beta$ -,  $\gamma$ -,  $\delta$ -tocotrienol in sealed ampules were obtained from F. Hoffmann-La Roche & Co., Basel, Switzerland.

**Procedure.** Sample Preparation. Samples of 250 g (mash, corn, pellets, grain, etc.) were ground to pass through a No. 30 sieve and were mixed thoroughly. Five-gram portions of the ground samples were accurately weighed, transferred into cellulose thimbles, placed on a Soxhlet containing 100 mL of alcohol, and extracted for 90 min. Samples of fat were saponified directly without preextraction. The sample extracts were refluxed with 2 g of ascorbic acid for 2-3 min. Ten grams of potassium hydroxide pellets was added and the samples were saponified for an additional 30 min.

The saponified extracts and two 40-mL water rinses were transferred into a 500-mL separatory funnel and extracted 2 times with 100 mL of petroleum ether (bp 36-58 °C). The extracts were combined and washed with several 100-mL portions of water until free of alkali. The petroleum ether extracts were filtered through 20 g of sodium sulfate and the separatory funnel was rinsed with two 20-mL portions of petroleum ether. The extracts were evaporated almost to dryness in a water bath at 45 °C under a stream of nitrogen and the residues dissolved in 10 mL of isooctane.

If necessary, the samples were diluted with isooctane to obtain a concentration of about 1  $\mu$ g/mL. This solution was used for HPLC analysis.

Standard Preparation. Individual standards were accurately weighed, dissolved, and diluted with isooctane to obtain a concentration of about  $1 \ \mu g/mL$ .

**Calculations.** Aspl  $\times 454 \times C \times f/(\text{Astd} \times 1000) =$  concentration of tocopherols (mg/lb) where C = standard concentration ( $\mu$ g/mL), f = dilution factor, Aspl = area of sample peak, Astd = area of standard peak, 454 = grams per pound, and 1000 = conversion from micrograms to milligrams.

#### DISCUSSION

The chromatographic separation of tocopherol and tocotrienol standards is presented in Figure 1. Typical chromatograms of tocopherols and tocotrienols extracted from feed ingredients are shown in Figure 2. The reproducibility of the HPLC system was determined by in-

Table I. Recovery of  $\alpha$ -Tocopherol<sup>a</sup> Added to Feed<sup>b</sup>

level, mg/lb	amount added, mg/5 g of feed	amount recovered, mg/5 g of feed	recove	ry, %
2	0.0296	0.0290		98.0
	0.0240	0.0240		100.0
	0.0224	0.0226		100.9
	0.0274	0.0269		98.2
	0.0220	0.0227		103.2
			av:	100.1
5	0.0547	0.0546		99.8
	0.0542	0.0567		104.6
	0.0480	0.0474		98.8
	0.0449	0.0437		97.3
	0.0490	0.0520		106.1
	0.0480	0.0465		96.9
			av:	100.6
10	0.0720	0.0715		99.3
	0.0960	0.0941		98.0
	0.1090	0.1100		100.9
	0.1080	0.1080		100.0
			av:	99.6
20	0.224	0.208		92.9
	0.240	0.237		98.8
	0.218	0.217		99.5
			av:	97.1
			total av:	99.4

<sup>*a*</sup> Solutions of  $\alpha$ -tocopherol in alcohol added to feed at the indicated levels. <sup>*b*</sup> Soybean meal containing 0.002 mg of  $\alpha$ -tocopherol/g.

Table II. Recovery of  $\alpha$ -Tocopherol Spray Dried<sup>a</sup> from Feed<sup>b</sup>

sample, mg/lb, a	dded	mg/lb recovered	% recovery
corn	11.3	11.5	101.8
corn	12.5	12.7	101.6
corn	15.2	14.9	98.0
alfalfa	11.4	11.1	97.4
alfalfa	9.9	9.5	96.0
alfalfa	11.3	11.1	98.2
cottonseed meal	9.8	9.9	101.0
			av: 99.1
corn	21.1	20.2	95.7
corn	22.5	22.8	101.3
corn	22.4	22.8	101.8
alfalfa	18.4	18.7	101.6
alfalfa	18.6	18.6	100.0
alfalfa	21.3	21.4	100.5
cottonseed meal	20.8	20.1	96.6
			av: 99.6

<sup>a</sup> Accurately weighed amounts of  $\alpha$ -tocopherol spray dried added to feed samples. <sup>b</sup> Base-line values: corn, 6.2 mg of  $\alpha$ -tocopherol/lb; alfalfa, 8.8 mg of  $\alpha$ -tocopherol/ lb; cottonseed meal, 4.3 mg of  $\alpha$ -tocopherol/lb.

jecting one sample of  $\alpha$ -tocopherol (1.42  $\mu$ g/mL) 6 times with a relative standard deviation of 0.9% obtained. Response was linear for  $\alpha$ -tocopherol within the range of 0.2-2.0  $\mu$ g/mL with a correlation coefficient of 0.9996 obtained from regression analysis. The average recovery of  $\alpha$ -tocopherol added to soybean meal, corn, alfalfa, and cottonseed meal was 99.4%. Individual recovery data and base-line values for the feeds used are shown in Tables I and II. The precision of the method was determined by analyzing one sample 6 times with a relative standard deviation of 2.7% obtained.

The tocopherol and tocotrienol values determined for 77 samples of 12 important feedstuffs are presented in Table III. The separation of the tocopherols is essential since each isomer has a specific vitamin E potency equivalent.  $\alpha$ -Tocopherol, which has the greatest vitamin E activity, is the dominant isomer in feed grains. There\_\_\_

The set of column interval interval column is column interval in			territorv <sup>a</sup>	α- tocopherol	۵- tocotrienol	β- tocopherol	$\gamma$ -	$\gamma$ -	δ- tocopherol
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soybean meal    13    0.61    3.6    race    0.9      soybean meal    49    0.79    5.8    trace    1.9      soybean meal    49    0.49    5.0    trace    1.7      soybean meal    49    0.45    2.7    1.1      soybean meal    49    0.40    1.4    1.5      soybean meal    49    0.40    1.4    1.5      soybean meal    49    0.40    1.4    1.5      fish meal    46    3.6    1.5    1.6      fish meal    6    3.7		soybean meal	10	0.75			6.3	trace	1.8
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lain meal1.31.31.0fish meal463.6fish meal493.5fish meal493.7meal and bone meal10NMA*cottonseed meal105.58.0105.58.01.1cottonseed meal105.37.71.05.37.71.0cottonseed meal105.37.7cottonseed meal102.21.0cottonseed meal102.720.9cottonseed meal102.720.9cottonseed meal106.622.4cortonseed meal106.622.4corn gluten meal106.622.4corn gluten meal102.720.9corn gluten meal102.010.0corn gluten meal102.19.7oats102.19.7oats102.19.7oats102.19.7oats492.63.60.26whole oats492.63.60.26whole oats492.63.60.26whole oats492.01.51.6alfalfa dehydrated1035.01.6.1alfalfa dehydrated103.01.7nilo103.01.61.7alfalfa dehydrated103.01.6alfalfa helydrated103.01.6		soy bean meal	49	0.40			1.4		
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fish meal fish meal (60%)40 491.3 		fish meal	49	3.5					
		fish meal	49	1.3					
		fish meal (60%)	49	3.7					
$\begin{array}{c c c c c c c c c c c c c c c c c c c $		meal and bone meal	10	$NMA^{b}$					
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cottonsed meal105.58.01.1cottonsed meal105.37.71.0cottonsed meal101.95.20.63cottonsed meal490.512.21.0cottonsed meal491.02.41.0cottonsed meal491.02.41.0corn gluten meal102.720.910.0corn gluten meal136.025.517.8corn gluten meal182.36.95.40.43oats102.19.70.430.43oats102.19.70.430.43oats102.19.70.430.45rolled oats493.23.6tracewhole oats493.23.6tracewhole oats493.23.6tracealfalfa dehydrated1016.41.71.5alfalfa dehydrated1035.015.34.2alfalfa dehydrated103.60.413.3alfalfa meal1814.51.6alfalfa meal1814.51.6milo103.0tracemilo491.20.68milo493.23.9otrace0.301.4alfalfa meal1814.5alfalfa meal1814.5alfalfa meal1814.5alfalfa meal182.9 </td <td></td> <td>cottonseed meal</td> <td>46</td> <td>8.3</td> <td></td> <td></td> <td>3.1</td> <td>0.35</td> <td></td>		cottonseed meal	46	8.3			3.1	0.35	
cottonseed meal105.37.71.0cottonseed meal490.512.20.63cottonseed meal491.02.4cottonseed meal492.02.4corn gluten meal106.622.416.7corn gluten meal136.025.517.8corn gluten meal136.020.50.43corn gluten meal102.010.00.43corn gluten meal102.010.00.43corn gluten meal102.010.00.43corn gluten meal492.36.95.40.43oats102.19.70.480.48whole oats492.63.60.260.48whole oats492.63.60.261.7ufalfa dehydrated1016.41.71.5tracealfalfa dehydrated1035.01.5.34.26.0alfalfa dehydrated1035.01.61.61.6alfalfa dehydrated103.0tracetracealfalfa meal491.51.61.7tracealfalfa meal491.50.301.41.5tracealfalfa meal491.50.301.41.5tracealfalfa farel491.50.301.41.5tracealfalfa farel491.50.301.41.5trace		cottonseed meal	10	5.5			8.0	1.1	
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cottonsect meal401.02.4corn gluten meal102.720.910.0corn gluten meal106.622.416.7corn gluten meal182.35.36.210.7corn gluten meal182.35.36.210.7corn gluten meal102.010.00.43corn gluten meal102.010.00.43corn gluten meal102.010.00.43cots102.19.70.45cots493.44.80.35rolled oats493.23.6tracewhole oats493.23.60.48whole oats493.23.60.27alfalfa dehydrated1016.41.71.5alfalfa dehydrated1035.015.34.2alfalfa dehydrated1035.015.34.2alfalfa meal4912.51.6alfalfa meal4913.76.4milo103.0tracemilo491.90.577.5barley103.610.50.30milo491.90.577.5barley103.610.50.30milo103.0tracemilo103.01.5tracemilo103.61.41.5barley103.61.6 <td< td=""><td></td><td>cottonseed meal</td><td>49</td><td>1.0</td><td></td><td></td><td>2.2</td><td>1.0</td><td></td></td<>		cottonseed meal	49	1.0			2.2	1.0	
corn gluten meal102.720.910.0corn gluten meal106.622.416.7corn gluten meal182.35.36.210.7corn gluten meal492.36.95.40.43oats102.010.00.00.48oats102.19.70.480.43oats102.19.70.480.43whole oats463.69.00.48whole oats493.23.6tracewhole oats492.63.60.26whole oats183.12.80.27alfalfa dehydrated1016.41.71.5alfalfa dehydrated1016.41.71.5alfalfa dehydrated1024.01.61.6alfalfa dehydrated1024.03.0tracealfalfa meal4912.51.61.6alfalfa meal4913.76.4milo103.0tracemilo491.90.577.5barley103.610.50.33milo491.90.577.5barley103.61.61.7barley103.61.22.2whote491.32.42.6milo103.0trace6.2milo103.0trace6.2milo		cottonseed meal	49	2.0			2.4 2.4		
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		corn gluten meal	10	2.7	20.9		10.0		
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		corn gluten meal	10	6.6	22.4		16.7		
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		corn gluten meal	13	6.0	25.5		17.8		
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		corn gluten meal	18	2.3	5.3		6.2	10.7	trace
oats102.010.0oats102.19.7oats493.44.80.35rolled oats463.69.00.48whole oats492.63.6tracewhole oats183.12.80.27alfalfa dehydrated1016.41.71.5alfalfa dehydrated1035.015.34.2alfalfa dehydrated1024.03.0tracealfalfa meal4912.51.6alfalfa meal1814.5alfalfa pelleted4913.76.4milo103.0tracemilo103.0tracemilo103.0tracemilo103.1tracemilo103.27.9oatey crimped103.27.9oatey crimped barley182.23.9wheat463.71.22.2wheat105.51.32.4wheat105.51.32.4wheat105.51.32.4wheat105.51.32.4wheat105.51.32.4wheat105.51.32.4wheat105.51.32.4wheat105.51.32.4wheat105.51.32.4wheat105.5		corn gluten meal	49	2.3	6.9		5.4		0.43
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		whole oats	49	2.6	3.6	0.26	nucc		
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$\begin{array}{cccccccccccccccccccccccccccccccccccc$		alfalfa meal	49	38.0		0.41	3.3		
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		alfalfa pelleted	49	13.7			6.4		
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		milo	10	3.0	trace		6.2		
$      barley & 10 & 4.4 & 12.9 & 0.68 & 1.7 \\      barley & 10 & 3.6 & 10.5 & 0.30 & 1.4 & 1.5 \\      barley crimped & 10 & 3.2 & 7.9 & 0.33 & 1.5 & trace \\      crimped barley & 18 & 2.2 & 3.9 & 0.79 \\      wheat & 46 & 3.7 & 1.2 & 2.2 \\      wheat & 10 & 5.5 & 1.3 & 2.4 & \\      wheat & 10 & 5.5 & 1.3 & 2.4 & \\      wheat & 10 & 5.3 & 1.4 & 2.6 & \\      whole wheat & 49 & 2.3 & 0.32 & 1.1 & \\      animal fat & 13 & 5.1 & trace & \\      animal fat & 13 & 5.1 & trace & \\      animal fat & 49 & 1.5 & 0.12 & 3.0 & 0.73 \\      animal fat & 49 & 1.2 & & 8.3 & \\      animal fat & 49 & 1.2 & & 3.5 & trace \\      animal fat & 40 & 1.5 & trace & trac$		milo	49	1.9	0.57		7.5		
$      barley crimped 10 3.6 10.5 0.30 1.4 1.5 \\      barley crimped 10 3.2 7.9 0.33 1.5 trace \\      crimped barley 18 2.2 3.9 0.79 \\      wheat 46 3.7 1.2 2.2 \\      wheat 10 5.5 1.3 2.4 \\      wheat 10 5.3 1.4 2.6 \\      whole wheat 49 2.3 0.32 1.1 \\      animal fat 13 5.1 trace \\      animal fat 49 1.5 0.12 3.0 0.73 \\      animal fat 49 1.5 8.3 \\      animal fat 49 1.2 3.5 trace \\      barley crimped barley 1.2 3.5 trace \\      barley crimped barley 1.4 1.5 \\      barley crimped barley 1.4 1.5 \\       barley crimped barley 1.4 1.5 \\      barley crimped barley 1.2 3.5 trace \\      barley crimped barley 1.4 1.5 \\      barley crimped barley 1.2 5 \\      barley crimped barley 1.4 1.5 \\      barley crimped barley 1.4 1.5 \\      barley crimped barley 1.4 1.5 \\      barley crimped barley 1.2 \\      barley crimped barley 1.4 1.5 \\      barley crimped barley crimped barley 1.4 1.5 \\      barley crimped barley crimp$		barley	10	4.4	12.9	0.68	1.7	1 7	
barley182.23.90.79wheat463.71.22.2wheat105.51.32.4wheat105.31.42.6whole wheat492.30.321.1animal fat135.1traceanimal fat491.50.123.0animal fat491.50.123.0animal fat491.23.5trace		barley crimped	10	3.0 3.9	10.5	0.30 0.32	1.4 1 5	1.9	trace
wheat463.71.22.2wheat10 $5.5$ $1.3$ $2.4$ wheat10 $5.3$ $1.4$ $2.6$ whole wheat49 $2.3$ $0.32$ $1.1$ animal fat13 $5.1$ traceanimal fat19 $1.5$ $0.12$ animal fat49 $1.5$ $0.12$ animal fat49 $1.5$ $0.12$ animal fat49 $1.2$ $8.3$ animal fat49 $1.2$ $3.5$		crimped barley	18	2.2	39	0.00	0.79		Made
wheat10 $5.5$ $1.3$ $2.4$ wheat10 $5.3$ $1.4$ $2.6$ whole wheat49 $2.3$ $0.32$ $1.1$ animal fat13 $5.1$ traceanimal fat49 $1.5$ $0.12$ $3.0$ $0.73$ animal fat49 $1.5$ $0.12$ $3.0$ $0.73$ animal fat49 $1.2$ $8.3$ $3.5$ trace		wheat	$\frac{10}{46}$	3.7	1.2	2.2	0.10		
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		wheat	10	5.5	1.3	2.4			
		wheat	10	5.3	1.4	2.6			
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		whole wheat	49	2.3	0.32	1.1			
animal fat409.3trace $0.11$ animal fat491.5 $0.12$ $3.0$ $0.73$ animal fat492.5 $8.3$ animal fat491.2 $3.5$ trace		animal lat	13	5,1	trace	0.11			
animal fat  49  2.5  8.3    animal fat  49  1.2  3.5  trace		animal lat (poultry)	40 10	9.3 15	trace	0.11	2.0		0.73
animal fat 49 1.2 3.5 trace		animal fat	49	2.5		0.12	8.3		0.70
	~ -	animal fat	49	1.2	_		3.5		trace

<sup>a</sup> Territories: 10 = California, Nevada, and Utah; 13 = Iowa; 46 = Alabama and Tennessee; 18 = Pennsylvania, New York, and New England; 49 = Ohio, Indiana, Kentucky, and Michigan. <sup>b</sup> NMA = no measurable amount.



Figure 2. Chromatograms of extracts from typical feedstuffs.

fore, it is important to know the natural  $\alpha$ -tocopherol content present in feedstuffs when recommending levels of vitamin E supplementation in animal rations.

The  $\alpha$ -tocopherol values obtained by HPLC were lower in most cases than values reported by Bunnell et al. (1968) for corn, corn gluten meal, oats, barley, and wheat. These grains contain significant amounts of  $\alpha$ -tocotrienol. The determination of  $\alpha$ -tocopherol using secondary magnesium phosphate chromatography reported by Bunnell et al. (1968) does not separate  $\alpha$ -tocopherol from  $\alpha$ -tocotrienol. thus accounting for the high values obtained. On the other hand, for feedstuffs containing no  $\alpha$ -tocotrienol such as soybean meal, fish meal, cottonseed meal, and animal fat, values obtained by HPLC are comparable to those of Bunnell et al. (1968).  $\alpha$ -Tocopherol and  $\alpha$ -tocotrienol values obtained by Slover (1971) on corn, barley, and oats are lower than those reported here. These low values are most likely due to GC methods that require extensive sample cleanup and derivatization with the possibility of metal-catalyzed oxidation of the tocopherols. The HPLC method reported requires a short extraction with no significant loss of tocopherol as proven by recovery data. Separation of each tocopherol and tocotrienol isomer was also obtained.

The importance of vitamin E in animal nutrition is well established. A recent study published by Adams (1982) using the method described herein showed that many cattle feedlot rations have low  $\alpha$ -tocopherol content. These low levels of  $\alpha$ -tocopherol intake were reflected in low plasma tocopherol levels found in cattle, indicating a need for vitamin E supplementation.

The data presented in Table III provide a comprehensive update of the tocopherol contents of major feedstuffs in the United States.

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**Registry No.**  $\alpha$ -Tocopherol, 59-02-9;  $\beta$ -tocopherol, 148-03-8;  $\gamma$ -tocopherol, 7616-22-0;  $\delta$ -tocopherol, 119-13-1;  $\alpha$ -tocotrienol, 1721-51-3;  $\gamma$ -tocotrienol, 14101-61-2.

## LITERATURE CITED

- Abe, K.; Yuguchi, Y.; Katsui, G. J. Nutr. Sci. Vitaminol. 1975, 21, 183.
- Adams, C. R. Feedstuffs 1982, 54 (18), 24.
- Ames, S. R. J. Assoc. Off. Anal. Chem. 1971, 54, 1.
- Bieri, J. G.; Poukka, R. K. H.; Prival, E. L. J. Lipid Res. 1970, 11, 118.
- Bunnell, R. H. Lipids 1971, 6, 245.
- Bunnell, R. H.; Keating, J. P.; Quaresimo, A. J. J. Agric. Food Chem. 1968, 16, 659.
- Carpenter, A. P., Jr. J. Am. Oil Chem. Soc. 1979, 56, 668.
- Cohen, H.; Lapointe, M. J. Assoc. Off. Anal. Chem. 1980, 63 (6), 1254.
- Eriksen, S. J. Assoc. Off. Anal. Chem. 1980, 63 (5), 1154.
- Lovelady, H. G. J. Chromatogr. 1973, 85, 81.
- Manz, U.; Phillipp, K. Int. J. Vitam. Nutr. Res. 1981, 51, 342.
- Slover, H. T. Lipids 1971, 6 (5), 291.
- Tangney, C. C.; Driskell, J. Contraception 1978, 16, 499.
- Thompson, J. N.; Hatina, J. J. Liq. Chromatogr. 1979, 2, 327.
  Vatassery, G. T.; Maynard, V. R.; Hagen, D. F. J. Chromatogr. 1978. 161, 299.
- Widicus, W. A.; Kirk, J. R. J. Assoc. Off. Anal. Chem. 1979, 62 (3), 634.

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