331

Office Memorandum • UNITED STATES GOVERNMENT

TO : W. P. Ratchford, Assistant to Director, EURDD DATE: October 15, 1958

FROM : Margaret M. Smoot, Information Div., ARS

SUBJECT: Copies of T.B. No. 958, "Preparation and Use of Leaf Meals from Vegetable Wastes," by J. J. Willaman et al

In response to your request of October 13 for copies of the above-entitled publication, we are sending you 40 copies under separate cover today.

This publication is out of print and the plates have been destroyed. We are keeping 10 copies in our file here for very special requests.

Attachment

Margaret M. Smoot

Preparation and Use of Leaf Meals From Vegetable Wastes

By
J. J. WILLAMAN
Head, Biochemical Division

and

RODERICK K. ESKEW
Head, Chemical Engineering and Development Division

Eastern Regional Research Laboratory
Bureau of Agricultural and Industrial Chemistry
Agricultural Research Administration

UNITED STATES
DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

Preparation and Use of Leaf Meals From Vegetable Wastes[1]

By J. J. WILLAMAN, *head, Biochemical Division,* and RODERICK K. ESKEW, *head, Chemical Engineering and Development Division, Eastern Regional Research Laboratory, Bureau of Agricultural* and *Industrial Chemistry, Agricultural Research Administration* [2]

In collaboration with R. HENRY MORRIS, 3d, *special assistant to the Director,* EDWARD G. KELLEY, *chemist,* D. A. COLKER, *chemical engineer,* N. C. ACETO, *chemical engineer,* and MONROE E. WALL, *chemist,* of the *Eastern Regional Research Laboratory;* and A. E. TOMHAVE, *poultry and animal husbandman,* and EDMUND HOFFMANN, *assistant poultry husbandman,* of the *Delaware Agricultural Experiment Station.*

CONTENTS

	Page
Introduction	2
CHAPTER 1	
Availability of vegetable wastes	2
Crop production	3
Vegetable wastes	14
CHAPTER 2	
Chemical composition of vegetable wastes and vegetable leaf meals	21
Previous work	21
Preparation of samples	21
Presentation of data	22
CHAPTER 3	
Preparation of vegetable leaf meals	53
The process	53
Experimental studies	54
Equipment	58
Operating procedure	62
Yields and analyses	65
Cost of processing	65
Other methods of processing	68
CHAPTER 4	
Use of vegetable leaf meals in poultry feeds	69
Run 1.—Preliminary investigation on the use of vegetable leaf meals in broiler rations	69
Run 2.—Broccoli leaf meal and carotene extracted from it as vitamin A supplements in broiler rations	72
Run 3.—Effects of various concentrations of broccoli leaf meal in broiler rations	74
Run 4.—Broccoli leaf meal as a substitute for alfalfa meal in commercial broiler rations	76
Run 5.—Spinach, rhubarb, pea vine, and beet leaf meals in broiler rations	77
Run 6.—Kale, mixed pea vine and lima bean vine, and supplemented broccoli leaf meals in broiler rations	79
Run 7.—Broccoli leaf meal in laying and breeding rations	81

[1] Submitted for publication December 16, 1947.

[2] The authors are indebted to Seabrook Farms and King Farms for material and suggestions, and to the National Canners Association for supplying information on the occurrence and disposal of wastes. They also acknowledge their indebtedness to the following members of this Laboratory: Reba Baum for carotene and riboflavin analyses; Margaret Heller for tocopherol analyses; C. O. Willits and W. L. Porter for protein, fiber, and ether extract determinations; G. W. Macpherson Phillips for technical advice and suggestions in the drying studies; and Rita Hurley for obtaining drying data.

777244°—48——1

CHAPTER 5

	Page
Carotene concentrates and other lipid products in vegetable leaf meals	84
Carotene	84
Chlorophyll	94
Phytol	95
Xanthophyll	95
Carotene concentrates and other lipid products in vegetable leaf meals—Continued	
Tocopherol (vitamin E)	96
Other lipids	98
Summary	98
Literature cited	99

INTRODUCTION

The Eastern Regional Research Laboratory has undertaken to find industrial uses for the 4 million tons of fresh wastes developed annually from the commercial production of vegetables. For convenience the wastes are classed in two groups—"production" waste and "processing" waste. Production waste in general consists of the leafy portions of the plant and occurs principally in the field, packing shed, or viner. Processing waste consists of culls, trimmings, peels, and debris incident to processing for canning, freezing, or dehydration. This bulletin deals largely with production waste.

Since leaves are far richer in potentially valuable materials than are stems or roots, these investigations have been largely confined to leafy wastes. It should be understood that the data were obtained mostly on vegetables grown in the Middle Atlantic States.

This bulletin is largely a compilation of reports and circulars published from time to time by this Laboratory on various phases of the problem of utilization of waste. Included are a survey of all types of wastes to determine their chemical composition and detailed analyses of certain selected wastes; a study of the drying characteristics of the various leaves and the design of a plant for the preparation of leaf meals of optimal quality; poultry feeding trials to determine the nutritive value of these meals and their compatibility in poultry rations; a survey of the quantity, kind, location, and season for production of the various wastes; and a study of their suitability for commercial use, either as feed or as raw material for the preparation of their individual chemical components.

CHAPTER 1

AVAILABILITY OF VEGETABLE WASTES

By R. Henry Morris, 3d, *special assistant to the Director*

This chapter gives information on the distribution, quantities, and seasonal availability of the leafy wastes incident to the commercial production and processing of certain vegetables, selected from the standpoint of nutritional value, abundance, and occurrence in large concentrations. The vegetables selected and the estimated wastes from some of them in 1944 are as follows:

	Thousand tons		Thousand tons		Thousand tons
Beets	120	Cauliflower	354	Turnips	4
Broccoli	36	Lima beans	292	Spinach	39
Cabbage	1,537	Peas	1,981		
Carrots	164	Rutabagas	4		

Data on crop production and processing in 1944, on which the estimates on wastes are based, are given wherever deemed advisable. More comprehensive crop production data can be obtained from the Bureau of Agricultural and Industrial Chemistry AIC–51 [3] and from the Bureau of Agricultural Economics.

Crop Production

To arrive at a sound basis for an estimate of the quantities and distribution of vegetable wastes, it is essential to know the quantities and location of the crops produced for fresh market and for processing. It is necessary to make a distinction between the crops produced for fresh market and those for each type of processing (canning, dehydration, and freezing), because there is an appreciable difference in the percentage of waste from the different types.

Table 1 gives data, by States, on the production of some vegetables for fresh market and for processing in 1944. In certain States these crops are produced largely for fresh market; in others they are produced primarily for processing. The factors in table 2 were used to convert the fresh-market container units to a tonnage basis. As few data are available by States on some crops for 1944, the estimated production for 1939 is given (table 3), based on the 1939 acreage as shown in the 1940 census of agriculture (*42*).[4] The data indicate the States which led in the production of these vegetables.

As vegetable waste is a low-value commodity, which rapidly deteriorates until it is processed, information on the quantities available in a limited, local section is of paramount importance to anyone having its utilization under consideration. Figures 1 to 15, inclusive, give a general idea of the location of the heavy crop-producing sections within the various States. Further detailed information on the production of certain of these crops by counties can be obtained from the State crop-reporting agencies.

As the percentage of waste varies with the type of processing, data on processed packs have been converted to the equivalent farm weights to provide a more accurate basis for the estimation of waste (table 4). By farm weight is meant the weight of that portion of the harvested crop prepared for shipment to either processing plants or fresh market. The fresh-market totals in table 4 were obtained by subtracting all the additional known processed quantities from the fresh-market quantities shown in table 1.

[3] Morris, R. H., 3d, Colker, D. A., and Chernoff, M. F. vegetable wastes—availability and utilization. Bureau of Agricultural and Industrial Chemistry AIC–51. 6 pp., illus. 1944. [Mimeographed.]

[4] Italic numbers in parentheses refer to Literature Cited, p. 99.

TABLE 1.—*Crop production, by States, for fresh market and processing in 1944* [1]

State	Beets		Cabbage		Carrots	Cauliflower	Kale	Lima beans		Peas		Spinach		State totals	
	Fresh market	Processing	Fresh market [2]	Processing	Fresh market [2]	Fresh market [2]	Fresh market [2]	Fresh market	Processing	Fresh market	Processing	Fresh market [2]	Processing	Fresh market	Processing
	Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
Maine		(3)									4,350				4,350
New York		63,100	254,000	41,400	51,875	28,342		3,312	200	7,260	37,800	2,835		347,624	142,500
Pennsylvania	10,764	(3)	35,400	(3)	15,750				700		15,830	11,133		73,047	16,630
New Jersey	10,140	14,800	41,700	(3)	9,600	4,403		3,600	5,080	1,155		9,801		80,399	19,880
Delaware									2,990		2,000				4,990
Maryland		(3)	6,700	(3)				2,048	1,500		12,100	1,854	1,900	10,602	15,500
Ohio		(3)	18,700	12,400	20,800				550		3,800			39,500	16,750
Wisconsin		54,300	90,500	32,900					1,170		113,440			90,500	201,810
Illinois		(3)	22,500	1,200	17,400				(3)		9,920	2,628		42,528	11,120
Indiana		800	4,800	1,500	1,250				(3)		3,920			6,050	6,220
Michigan		12,900	51,200	4,500	21,000	3,515			1,120		8,250			75,715	26,770
Missouri		(3)	5,200	(3)								2,097		7,297	
Iowa		(3)	7,000	(3)							1,870			7,000	1,870
Nebraska		(3)													
Minnesota		(3)	12,200	2,000	1,725				(3)		15,750			13,925	17,750
Virginia	598	(3)	21,000	(3)			7,398	560	1,510	195	1,540	9,234	1,100	38,985	4,150
North Carolina	1,040	(3)	40,200	(3)				144	(3)	240				41,624	
South Carolina	2,080		11,800					1,920	(3)	1,350				17,150	
Georgia		(3)	19,200					992	(3)	630				20,822	
Florida			166,800					5,520		2,250				174,570	
Alabama			5,000											5,000	
Mississippi		(3)	39,800							315				40,115	
Tennessee		(3)	20,800	(3)					(3)					20,800	
Kentucky			1,200											1,200	
Louisiana	1,638	(3)	24,500		3,950				(3)			630		30,718	
Texas	38,272	(3)	208,800	(3)	74,400	2,220				2,370		55,332	9,000	381,394	9,000
Oklahoma		(3)										3,204	25,400	3,204	25,400
Arkansas									(3)			2,376	20,100	2,376	20,100
New Mexico			6,100		14,650									20,750	
Colorado		(3)	61,300	1,900	11,500	19,240			(3)	18,000	4,090	4,320		114,360	5,990
Utah		(3)	5,500	(3)	2,475				540	135	24,070			8,110	24,610
Idaho					3,300				(3)	6,585				9,885	
California		(3)	167,900		317,175	91,409			3,730	38,565	4,330	13,446	49,400	628,495	57,460
Oregon		24,800	12,600	(3)	8,000	7,566			(3)	1,980	46,750			30,146	71,550
Washington		(3)	10,000	2,400	17,275	3,478			300	4,890	46,920	7,227		42,870	49,620
Arizona			16,000		43,800	10,064				6,240				76,104	
Other States		14,100		7,800					6,610		15,430				43,940
U. S. total	64,532	184,800	1,388,400	108,000	635,925	170,237	7,398	18,096	26,000	92,160	372,160	126,117	106,900	2,502,865	797,860

[1] Calculated from data taken from U. S. Bureau of Agricultural Economics monthly reports on crop production.
[2] Includes undetermined quantities used for processing.
[3] Included in "Other States."

TABLE 2.—*Factors used to convert unit measures to pounds and tons*

Crop	Unit	Pounds per unit	Tons per unit
Beets	Bushel	52	0.026
Broccoli	Crate	42	.021
Carrots	Bushel	50	.025
Cauliflower	Crate	37	.0185
Kale	Bushel	18	.009
Lima beans [1]	do	32	.016
Peas [1]	do	30	.015
Spinach	do	18	.009
Tomatoes	do	53	.0265

[1] Unshelled.

TABLE 3.—*Estimated crop production in 1939* [1]

State	Broccoli	Kale	Rutabagas	Turnips
	Tons	*Tons*	*Tons*	*Tons*
Maine	7		72	1,096
New Hampshire	7			160
Vermont	3		9	176
Connecticut	145	80		1,480
Massachusetts	40	48		3,480
Rhode Island	290			200
New York	1,069	310	423	4,168
Pennsylvania	2,524	48	1,206	4,256
New Jersey	3,425	128	381	3,208
West Virginia		42	9	248
Delaware	528	6		88
Maryland	462	1,152	549	2,712
Ohio	46	333	27	6,944
Wisconsin	3		1,242	224
Illinois	76		9	1,936
Indiana		99	27	1,904
Michigan	36	13	1,224	1,648
Missouri		150		2,328
Kansas		10		2,104
Iowa				336
Nebraska	3		36	328
Minnesota	7		7,758	128
North Dakota			63	16
Virginia	3,105	9,270	1,674	2,632
North Carolina	512	400	72	2,320
South Carolina	983		54	3,480
Georgia	7		54	16,192
Florida	257	19	144	4,736
Alabama			81	7,752
Mississippi			54	8,400
Tennessee	3	890		2,520
Kentucky		1,882		1,312
Louisiana	861		63	7,352
Texas	7,240	10	99	18,344
Oklahoma	3			1,008
Arkansas	3	3		2,872
New Mexico	66		108	320
Colorado	162		180	2,216
Utah	7			104
Idaho			72	56

[1] Calculated from data in the 1940 U. S. Census of Agriculture (*42*).

TABLE 3.—*Estimated crop production in 1939* [1]—Continued

State	Broccoli	Kale	Rutabagas	Turnips
	Tons	*Tons*	*Tons*	*Tons*
Wyoming	----------	----------	18	40
Montana	----------	----------	225	112
California	17, 150	51	783	7, 160
Oregon	647	70	27	840
Washington	195	61	1, 503	1, 112
Nevada	----------	----------	----------	16
Arizona	693	----------	9	664
Other States	----------	29	----------	----------
Total	40, 565	15, 105	18, 261	130, 728

[1] Calculated from data in the 1940 U. S. Census of Agriculture (*42*).

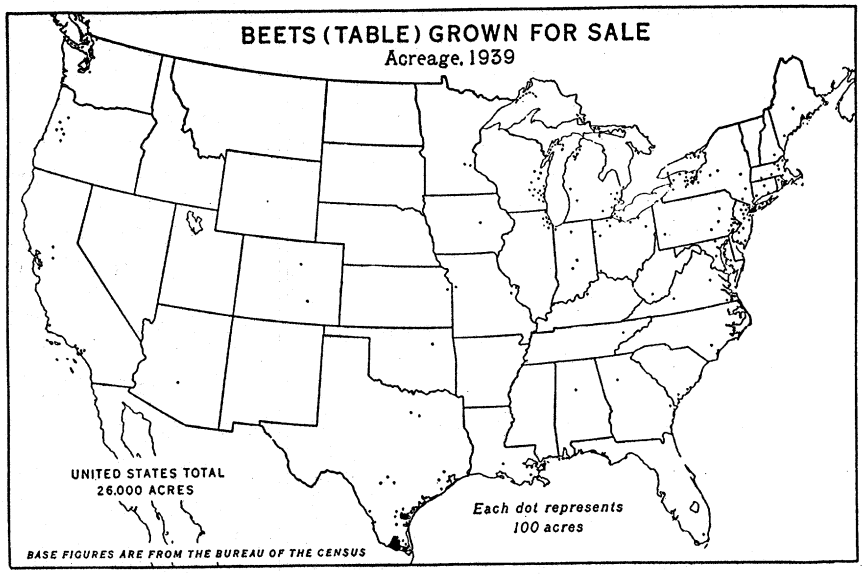


FIGURE 1.—Location of sections producing beets.

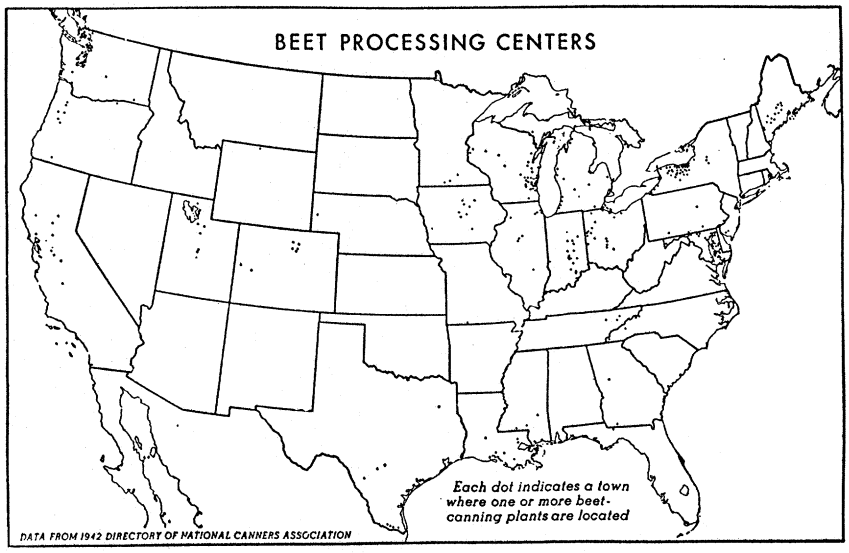


FIGURE 2.—Location of beet-processing centers.

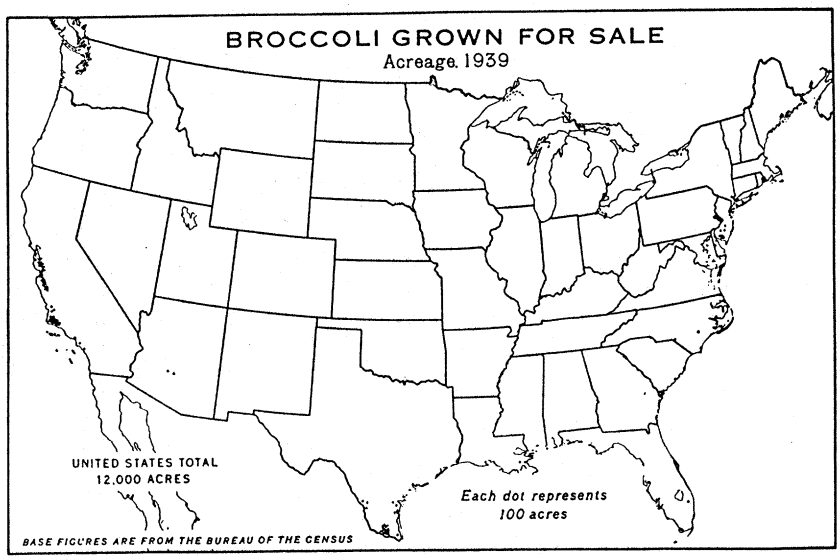


FIGURE 3.—Location of sections producing broccoli.

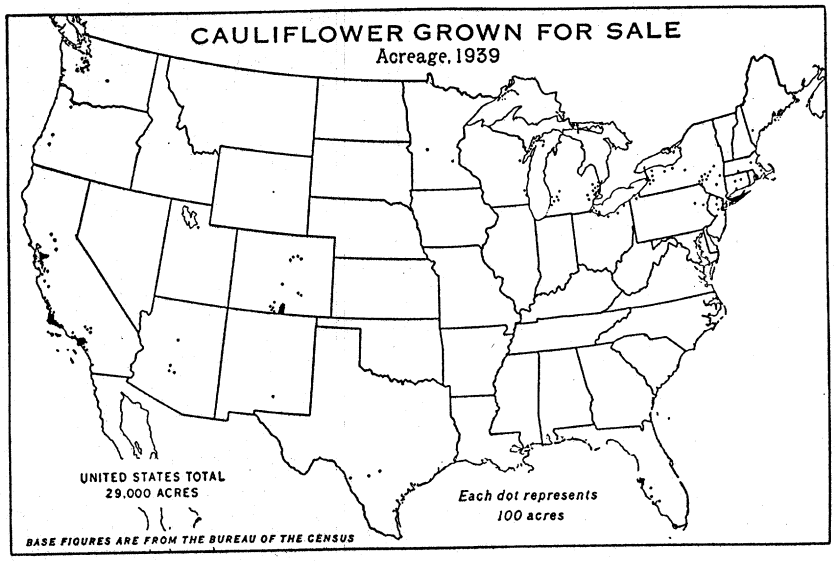


FIGURE 4.—Location of sections producing cauliflower.

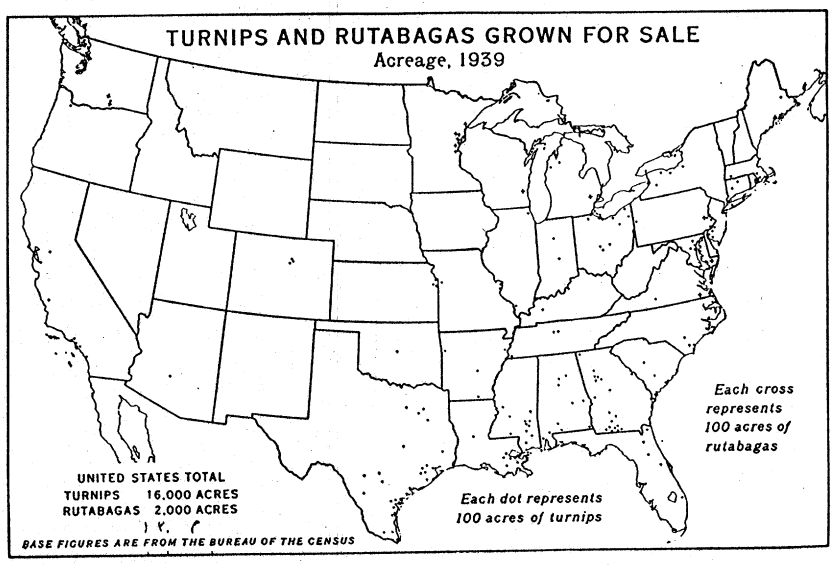


FIGURE 5.—Location of sections producing turnips and rutabagas.

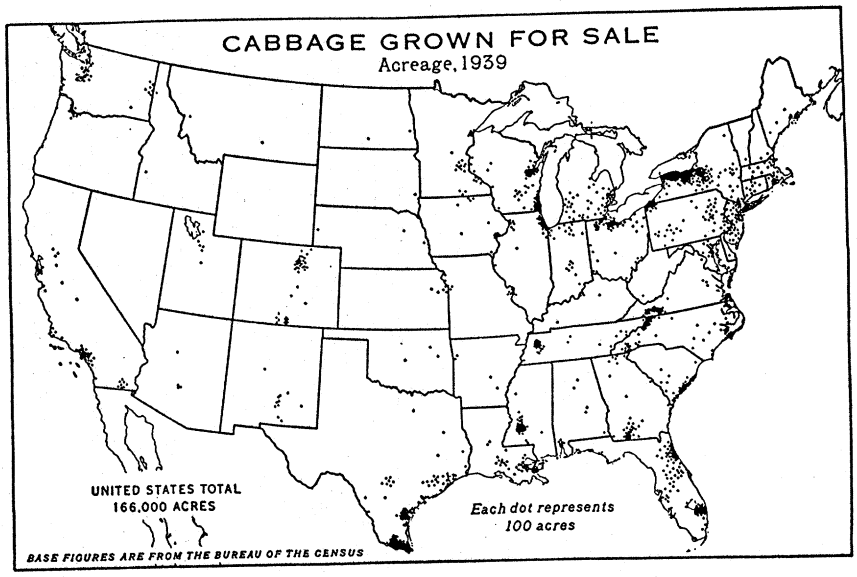


FIGURE 6.—Location of sections producing cabbage.

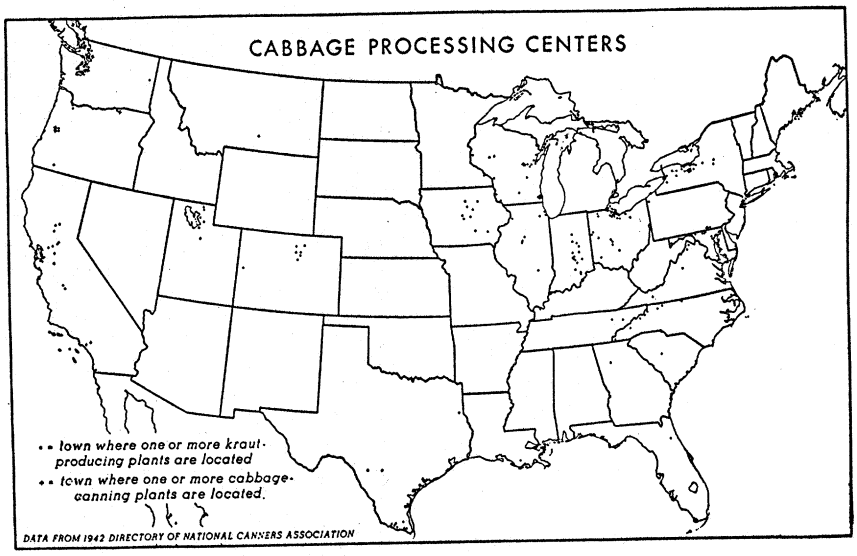


FIGURE 7.—Location of cabbage-processing centers.

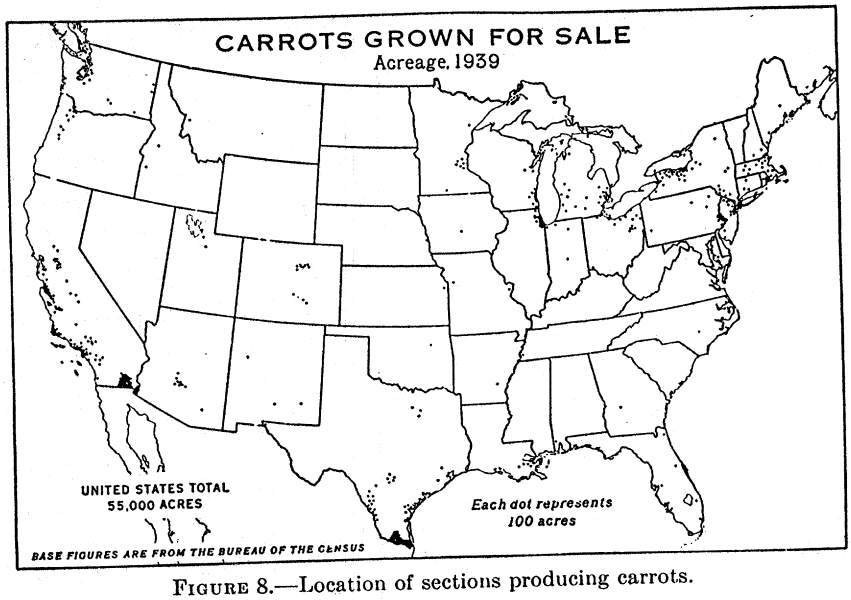


FIGURE 8.—Location of sections producing carrots.

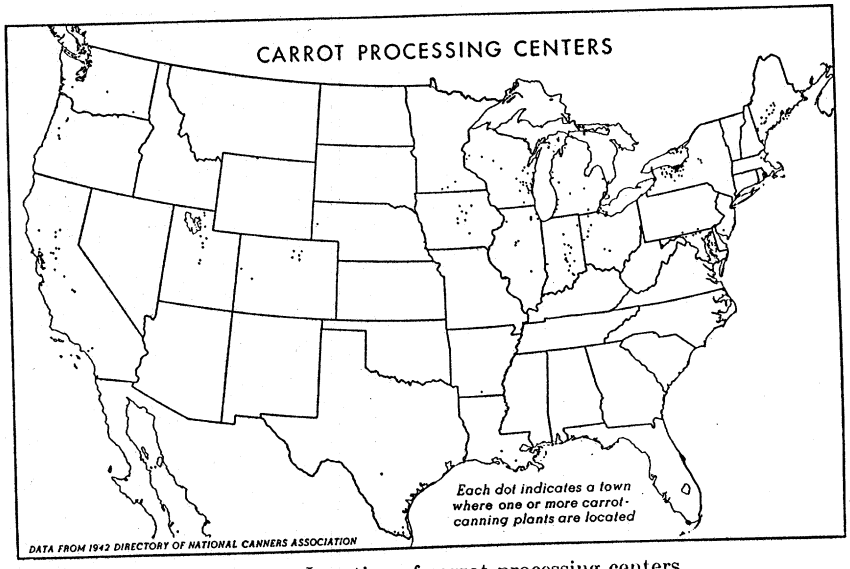


FIGURE 9.—Location of carrot-processing centers.

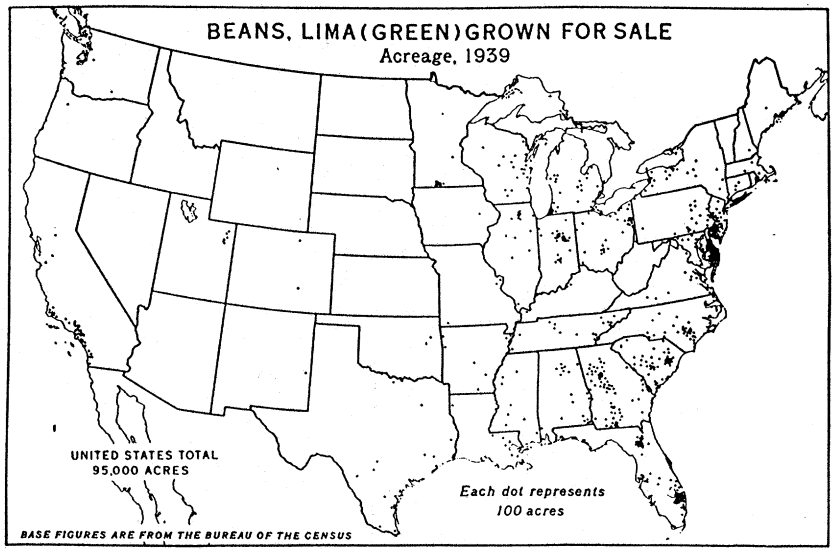


FIGURE 10.—Location of sections growing lima beans.

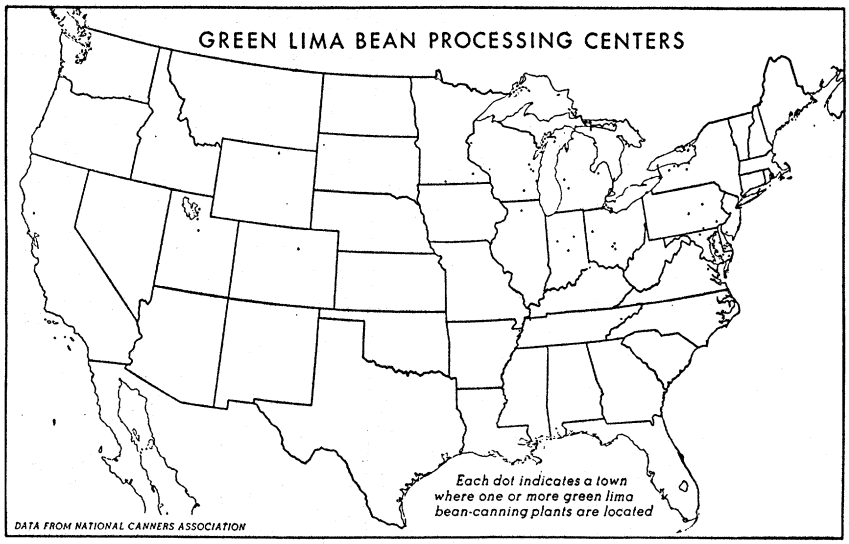


FIGURE 11.—Location of lima bean-processing centers.

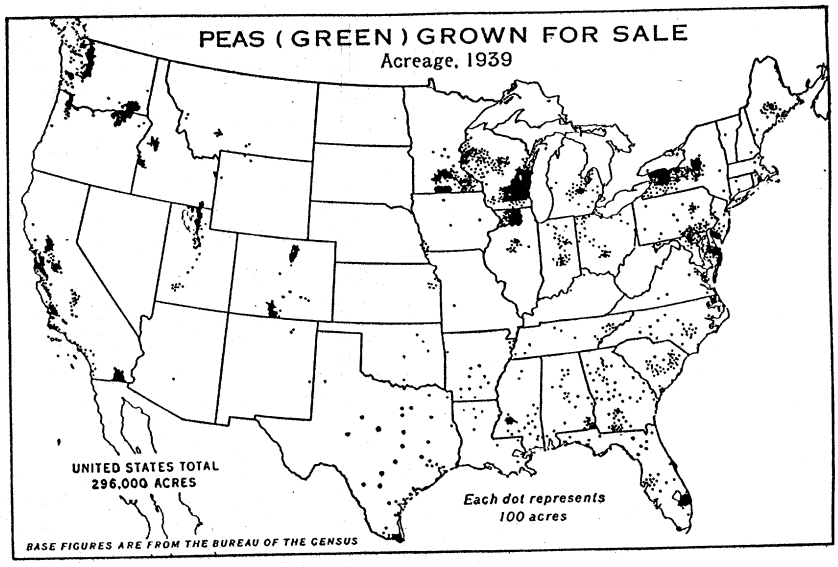


FIGURE 12.—Location of sections growing peas.

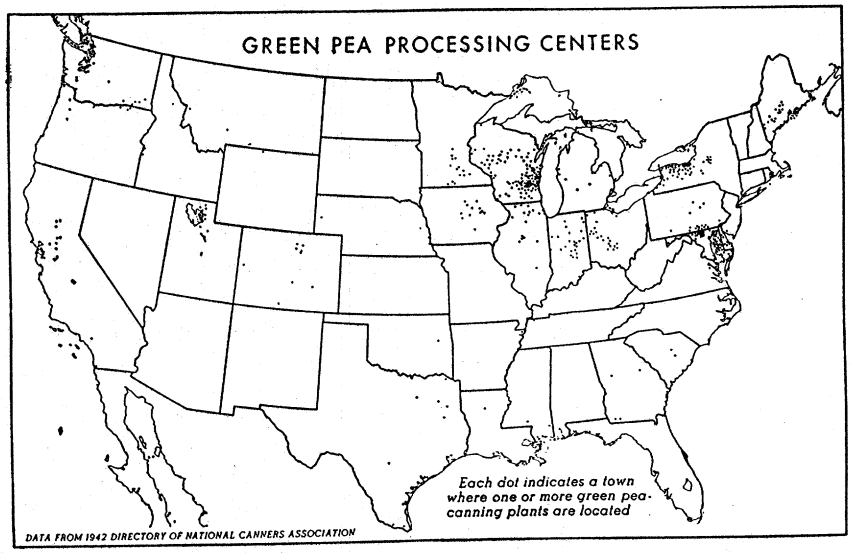


FIGURE 13.—Location of pea-processing centers.

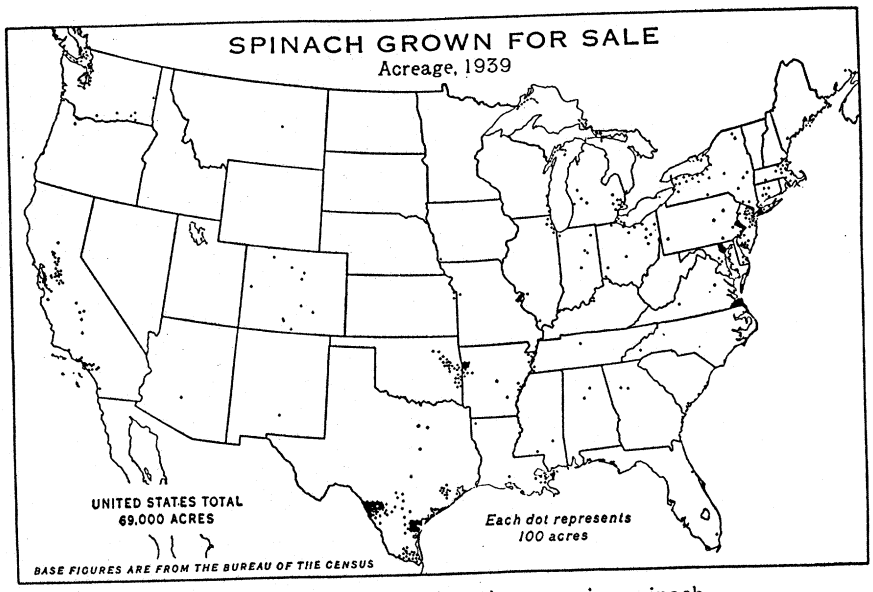


FIGURE 14.—Location of sections growing spinach.

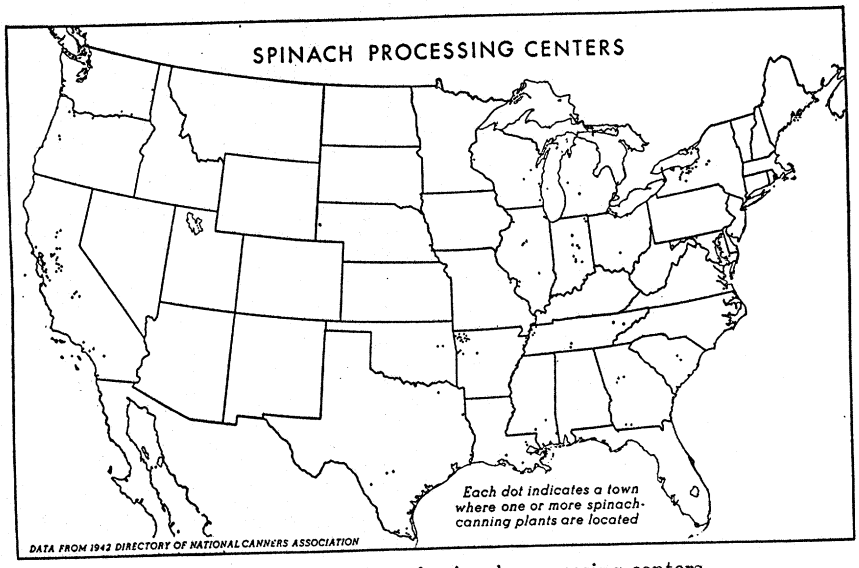


FIGURE 15.—Location of spinach-processing centers.

TABLE 4.—*Estimated farm weights of crops produced for fresh market and processing in 1944*

Vegetable	Fresh market	Processed				Total
		Canned	Dehydrated	Frozen	Total	
	Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
Beets	64, 532	151, 878	44, 408	--------	196, 286	260, 818
Broccoli	29, 492	--------	--------	6, 218	6, 218	35, 710
Cabbage	1, 315, 050	[1] 108, 000	73, 350	--------	181, 350	1, 496, 400
Carrots	508, 327	44, 446	81, 930	1, 222	127, 598	635, 925
Cauliflower	162, 204	--------	--------	8, 033	8, 033	170, 237
Kale	7, 398	--------	--------	--------	--------	7, 398
Lima beans	18, 096	17, 614	--------	15, 558	33, 172	51, 268
Peas	92, 160	331, 794	--------	41, 436	373, 230	465, 390
Rutabagas	--------	--------	10, 806	--------	10, 806	10, 806
Spinach	126, 117	106, 900	--------	30, 717	137, 617	263, 734
Miscellaneous [2]	--------	--------	--------	3, 712	3, 712	3, 712
Total	2, 323, 376	760, 632	210, 494	196, 896	1, 078, 022	3, 401, 398

[1] Sauerkraut.
[2] Includes beets, broccoli, collards, kale, mixed vegetables, turnip greens, celery, and okra.

The number of plants processing the vegetables selected for this survey is shown by States in table 5. Owing to the fact that many of the plants pack more than one vegetable and use more than one process, it is not possible to total these figures horizontally, that is, by States.

VEGETABLE WASTES

NATURE

The vegetable waste investigations of the Eastern Regional Research Laboratory have been confined mainly to the leafy green wastes that occur at the farm, packing shed, and viner, as these are by far the richest in valuable nutritional constituents. In this chapter, however, all the wastes are included, as it is planned to investigate the feasibility of utilizing the other types of wastes, which occur largely at the processing plants.

Because of the rapid accumulation and extremely perishable nature of most of this material, it must be disposed of as quickly as possible for sanitary reasons. Moreover, if its nutritional value is to be used to the fullest extent, it must be fed immediately or processed with the minimum of delay.

DISTRIBUTION

Only a rough approximation of the quantities of wastes in different localities is feasible, inasmuch as there is a wide variation in farm and processing plant practices, crop yields, quality and potential value of raw material, unharvested crops, and many other factors. The information assembled here should prove useful in determining the most suitable location for the commercial utilization of these wastes. More specific detailed information pertaining to any particular locality can be obtained from State and county agencies and local farms and processing plants.

TABLE 5.—*Number of plants, by States, that processed various crops in 1943* [1]

State	Beets			Broccoli		Cabbage		Carrots			Cauliflower		Kale		Lima beans		Peas		Rutabagas and turnips		Spinach	
	Canneries	Frozen-food packers	Dehydration plants	Canneries	Frozen-food packers	Canneries	Dehydration plants	Canneries	Frozen-food packers	Dehydration plants	Canneries	Frozen-food packers	Canneries	Frozen-food packers	Canneries	Frozen-food packers	Canneries	Frozen-food packers	Canneries	Dehydration plants	Canneries	Frozen-food packers
Maine	3	----	----	----	1	----	----	2	----	----	----	----	----	----	1	1	2	2	----	----	----	1
Massachusetts	----	----	----	----	1	----	----	1	----	----	----	1	----	----	1	----	----	----	----	----	----	1
New York	25	1	3	----	6	17	3	26	3	----	1	2	----	----	5	7	32	8	----	----	6	6
Pennsylvania	5	----	----	----	----	4	----	2	----	----	----	----	----	----	5	1	19	1	----	----	1	1
New Jersey	3	1	3	1	1	----	----	2	1	2	1	1	1	1	1	1	1	1	----	1	1	1
Delaware	----	----	----	----	1	----	----	----	----	----	----	1	----	----	6	1	6	1	----	----	----	1
Maryland	13	----	----	----	----	5	----	11	----	----	----	----	3	----	16	----	34	----	11	----	14	----
Ohio	6	----	1	----	----	10	1	4	----	1	1	----	----	----	8	----	9	----	----	----	1	----
Wisconsin	23	1	1	----	----	11	----	18	1	1	1	----	----	----	5	----	91	----	----	1	3	----
Illinois	3	----	----	----	----	5	----	4	----	----	----	----	----	----	5	----	11	----	----	----	----	----
Indiana	4	----	----	----	1	5	----	6	----	1	----	----	----	----	3	1	17	1	1	----	1	1
Michigan	9	----	----	----	----	1	----	10	----	----	----	1	----	----	2	4	6	4	----	----	3	2
Missouri	2	----	----	----	----	1	----	----	----	----	----	----	----	----	----	----	1	----	----	----	1	----
Iowa	1	----	----	----	----	2	----	1	----	----	----	----	----	----	1	----	2	----	1	----	1	----
Nebraska	2	----	----	----	----	----	----	2	1	----	----	----	----	----	2	----	4	1	----	----	2	----
Minnesota	1	----	1	----	----	2	----	2	----	----	----	----	----	----	1	4	6	4	----	1	----	----
Virginia	----	----	----	----	1	----	----	----	1	----	----	1	1	----	5	1	8	1	4	----	4	1
North Carolina	----	----	----	----	----	2	1	----	----	----	----	----	----	----	----	----	----	----	1	----	----	----
South Carolina	----	----	----	----	----	1	----	----	----	----	----	----	----	----	----	----	1	----	2	----	1	----
Georgia	1	----	----	----	----	----	----	1	----	----	----	----	----	----	2	----	1	----	10	----	----	----
Florida	----	----	----	----	----	----	2	1	----	1	----	----	----	----	1	----	1	----	2	----	1	----
Alabama	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2	1	1	1	3	----	----	----
Mississippi	3	----	----	1	----	----	----	----	----	1	----	----	1	----	----	----	1	----	4	----	3	----

[1] Summary of data obtained from:
Canners Directory (*27*).
Frozen Food Directory (*1*).
War Food Administration (private communication).

TABLE 5.—*Number of plants, by States, that processed various crops in 1943* [1]—Continued

State	Beets			Broccoli		Cabbage		Carrots			Cauliflower		Kale		Lima beans		Peas		Rutabagas and turnips		Spinach	
	Canneries	Frozen-food packers	Dehydration plants	Canneries	Frozen-food packers	Canneries	Dehydration plants	Canneries	Frozen-food packers	Dehydration plants	Canneries	Frozen-food packers	Canneries	Frozen-food packers	Canneries	Frozen-food packers	Canneries	Frozen-food packers	Canneries	Dehydration plants	Canneries	Frozen-food packers
Tennessee	3	----	----	----	1	2	----	----	----	----	----	----	----	----	----	----	----	----	4	----	5	1
Kentucky	----	----	----	----	----	1	----	----	----	----	----	----	----	----	----	----	----	----	1	----	1	----
Louisiana	6	----	----	1	----	1	----	1	----	----	----	----	----	----	1	----	1	----	2	----	4	----
Texas	9	----	----	----	----	3	----	7	----	1	----	----	----	----	3	----	2	----	14	----	16	----
Oklahoma	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1	----	2	----	4	----
Arkansas	----	----	----	----	----	----	----	----	----	----	----	----	4	----	2	----	2	----	15	----	23	----
Colorado	2	----	----	----	----	2	----	1	----	----	----	----	----	----	----	----	3	----	----	----	----	----
Utah	5	----	----	----	----	2	----	6	----	----	----	----	----	----	4	2	13	2	----	----	----	----
Idaho	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1	----	----	----	----	----
Wyoming	1	----	----	----	----	----	----	1	----	----	----	----	----	----	1	----	1	----	----	----	----	----
Montana	----	----	1	----	----	1	----	----	----	1	----	----	----	----	----	----	2	----	----	----	----	----
California	9	4	2	1	10	7	9	16	5	18	----	9	----	1	5	7	9	5	1	1	29	9
Oregon	8	----	3	----	5	3	----	7	4	2	----	5	----	----	2	4	4	5	----	----	6	6
Washington	7	4	----	----	24	3	----	3	20	2	----	21	----	2	2	20	14	27	----	1	1	26
Total	154	11	15	4	52	91	16	135	36	31	4	42	10	4	92	55	307	64	78	5	132	57

[1] See footnote on p. 15.

Table 6 shows the estimated quantity of waste available from different sources, obtained by the application of waste factors to the estimated farm weights of crops shown in table 4. These factors are based on information obtained from fresh market packing plants, processing plants, and trade organizations and publications. Wherever possible, allowance has been made for variations in the production and processing of vegetables in different parts of the country.

As indicated in table 6, the wastes occur at the farm, viner, packing plant, and processing plant. The viners, generally owned by the processing plants, are strategically located to handle lima bean and pea vines directly from the field.

It should be taken into account that in addition to the quantities of wastes indicated in table 6, significant quantities are available from crops not harvested because of unsatisfactory conditions, such as poor quality, unfavorable markets, or labor shortage.

Figures 1 to 15, inclusive, indicate where wastes are available in quantity by showing where the crops are grown for fresh market and for processing.

SEASONAL AVAILABILITY

It is desirable to extend the production period of any commercial operation as long as possible in order to reduce overhead costs. Therefore, information is included on the length of time that these waste materials will probably be available for processing in different sections of the country.

Figures 16 and 17 indicate the periods of the year in which the waste from each type of selected vegetable is available in different regions. Figure 16 shows the peak of the growing season by regions; figure 17 shows the operating dates for packing by States. These data naturally vary somewhat from year to year, but they should be useful as a guide.

PRESENT UTILIZATION

A certain quantity of the waste occurring on the farm is used for feed if it is suitable and easy to collect. In many cases, however, it can be used only as a supplementary feed. It is frequently plowed under to enrich the soil. In this case, there is the possible danger that it may cause an infection of the soil, especially if the material has not been composted or the crops are not rotated.

Disposal of the refuse from the processing plant usually represents a much more serious problem, owing to the large quantities involved and its rapid decomposition, which may constitute a definite menace to health. If the distance is not too great, this material is frequently returned to the neighboring farms for use as feed or soil enrichment. Otherwise, it may be either hauled to a dump or treated for subsequent disposal in a municipal or processing-plant sewage system. As a rule, disposal of this material entails a definite expense to the processor, especially if it necessitates initial capital expenditure for the installation of a sewage-treatment plant. Some packing and processing plants dispose of their pea and lima bean vines and other suitable materials by feeding them to cattle, which they keep for this purpose.

Various waste materials are now being dried commercially for feed. An outstanding example is tomato waste, which several plants are drying in large quantities for this purpose.

TABLE 6.—*Estimated quantity of vegetable waste produced in 1944*

Vegetable	Fresh market waste			Processing waste			Total
	Field	Packing plant	Total	Field	Processing plant	Total	
	Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
Beets	3, 872	1, 936	5, 808	54, 950	58, 885	113, 835	119, 643
Broccoli	17, 695	11, 806	29, 492	3, 731	2, 798	6, 529	36, 021
Cabbage	1, 315, 050	----------	1, 315, 050	181, 350	40, 671	222, 021	1, 537, 071
Carrots	35, 583	50, 833	86, 416	47, 211	30, 144	77, 355	163, 771
Cauliflower	324, 408	8, 110	332, 518	16, 066	5, 623	21, 689	354, 207
Lima beans	52, 020	905	52, 925	[1] 237, 520	1, 737	239, 257	292, 182
Peas	221, 970	----------	221, 970	[1] 1, 739, 800	18, 869	1, 758, 669	1, 980, 639
Rutabagas	----------	----------	----------	2, 701	1, 243	3, 944	3, 944
Spinach	----------	2, 582	2, 582	----------	36, 124	36, 124	38, 706
Miscellaneous [2]	----------	----------	----------	----------	1, 856	1, 856	1, 856
Total	1, 970, 598	76, 163	2, 046, 761	2, 283, 329	197, 950	2, 483, 079	4, 528, 040

[1] Viner.
[2] Includes beets, broccoli, collards, kale, mixed vegetables, turnip greens, celery, and okra.

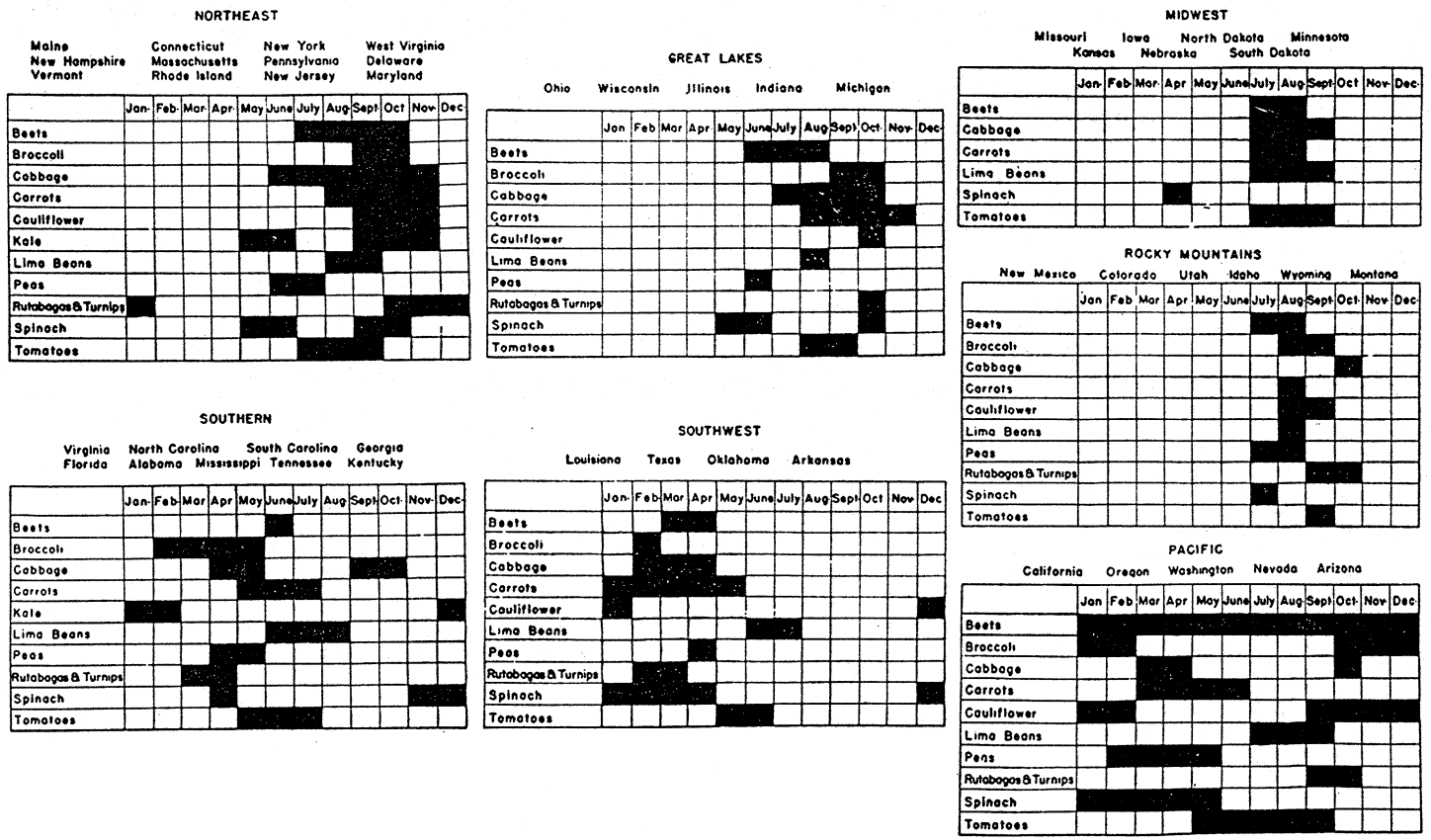


FIGURE 16.—Seasonal availability of crops.

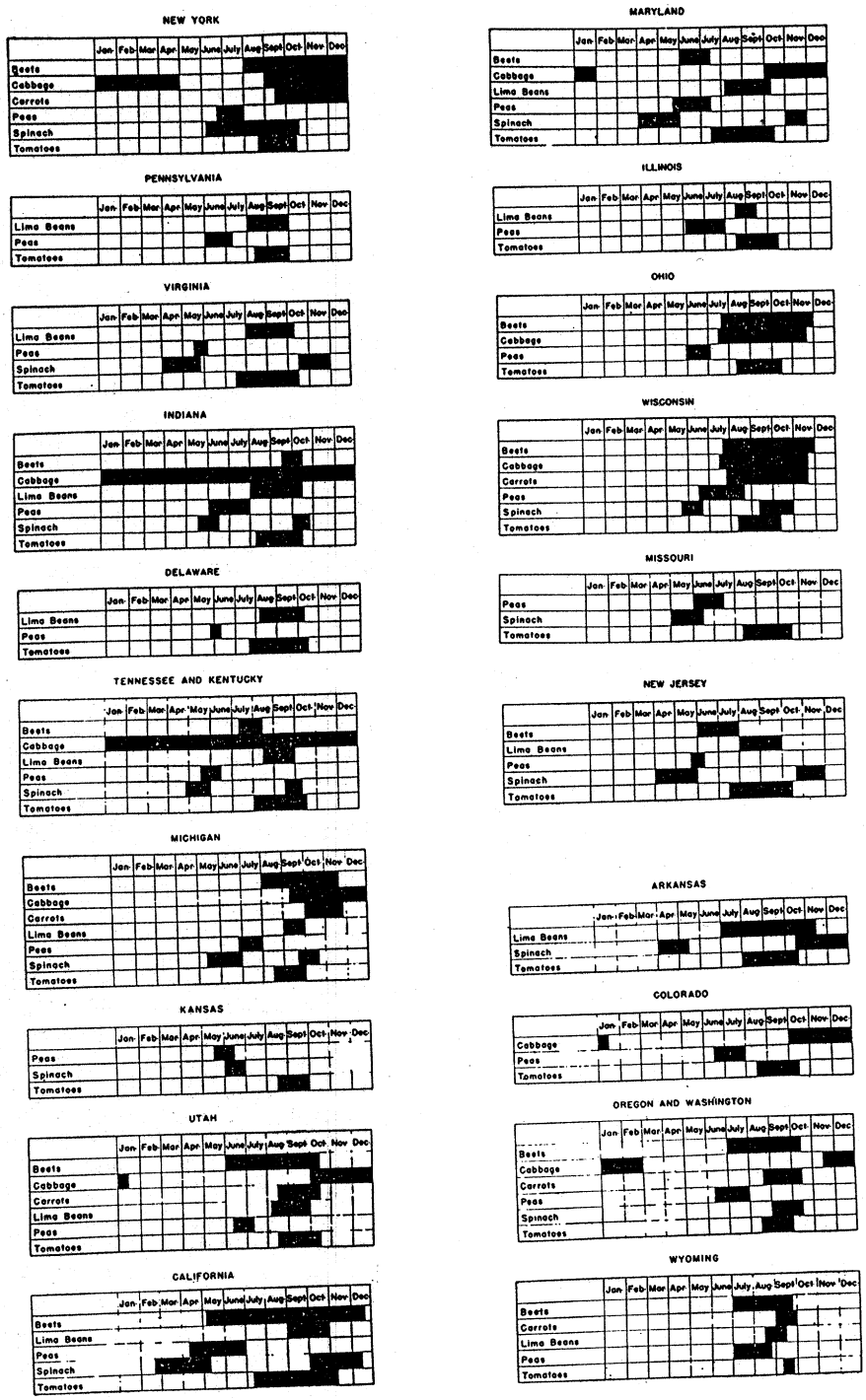


FIGURE 17.—Opening and closing dates of packing season.

CHAPTER 2

CHEMICAL COMPOSITION OF VEGETABLE WASTES AND VEGETABLE LEAF MEALS

By Edward G. Kelley, *chemist*

Previous Work

Many analyses have been made of the edible portions of vegetable crops, but few of the strictly waste portions have been analyzed. Where the two overlap, some analyses are available for comparative purposes, as in spinach (*3, 5, 6, 7, 8, 10, 14, 17, 26, 28, 32, 33, 34, 38, 50, 51*), turnip tops (*7, 8, 38, 48, 50*), and beet leaves[5] (*8, 14, 34, 50, 51*). Pea pods have been investigated for their possible value (*47*); cull peas in the waste have values similar to those of the edible pea, which has been studied in some detail (*5, 6, 10, 14, 17, 21, 26, 32, 51*). Protein and oxalic acid in broccoli leaves have been determined (*6, 7, 10, 14, 17, 21, 26, 28, 32, 51*). Rhubarb petioles have been analyzed for various constituents, and brief mention has been made of the oxalic-acid content of the leaves (*6, 7, 17, 50*). Collard (*50*), corn (*2, 6, 14, 21*), kale (*6, 7, 32, 50*), lima bean ((*5, 6, 7, 17, 51*), and cabbage (*6, 7, 10, 14, 17, 21, 26, 32, 50*) have also been previously studied.

Preparation of Samples

The fresh wastes used in the work described here were obtained in different ways. Carrot and beet tops, for instance, were gathered in baskets from the fields where the plants were grown; broccoli and rhubarb were collected from the ends of the belts at packing houses; pea vine and lima bean vine wastes were obtained from viner stations. Because the wastes from kale and turnips were not obtainable, the plants were grown for this study or bought on the wholesale market.

The fresh materials were prepared for analysis by two methods. Some were separated by hand into leaves, petioles, stems, and pods, and dried to 5- to 10-percent moisture content. They were then ground and stored for subsequent study.

Most types of fresh material were also prepared by a pilot-plant drying and screening procedure, called fractional drying and trommeling, which gave two fractions, one essentially leafy, the other stemmy. When the material had dried to the stage at which the leaf blade was brittle, while the petioles were still damp and resistant to breaking, it was placed in a rotating cylindrical screen or trommel with 2-inch pebbles, which was rotated until the leafy fraction had passed through the screen. The residue was returned to the drier and dried to the low moisture content necessary for grinding and storing.

All the data in this chapter were obtained on material prepared by these methods. Subsequently, a modification of the trommeling phase was introduced, as described in chapter 3. The products pro-

[5] Pepkowitz, Leonard P., Larson, Russel E., Gardner, Josephine, and Owens, Geraldine M. the carotene and ascorbic-acid content of vegetable varieties: ii. peppers and beets. R. I. Agr. Expt. Sta. 6 pp. [n. d.] [Mimeographed.]

duced by the modified method are comparable in all respects with those produced by trommeling.

Presentation of Data

Since beet, broccoli, carrot, kale, lima bean, pea, rhubarb, spinach, turnip, and celery wastes have been investigated in greatest detail, each of these is dealt with separately. Cabbage, cauliflower, collard, parsnip, and sweet corn wastes are discussed under miscellaneous wastes, since relatively little work has been done on them.

Data on loss of carotene in a few wastes during storage are presented. A brief discussion of oxalic acid and tocopherol, which have been only partially investigated, is included to indicate the work now in progress on the chemical composition of vegetable wastes.

BEET TOPS

Beet tops represent a major waste product in the vegetable industry. Beets for fresh market provide little waste because they are generally marketed with the tops; but beets for bulk sale or for processing are usually topped in the field, where the tops are left in small piles. Since gathering these tops, even on a small scale, would be impractical, their successful utilization would require a change in the present harvesting technique. Cutting the tops with a mowing machine with attached belt and trailer would be the most satisfactory method, since it would eliminate much of the dirt that is mixed with the material gathered from the ground. Fairly clean leaves could also be obtained by topping at the packing house, a procedure formerly used to a considerable extent. Washed handstripped leaves and those cut before the beets are pulled are rich in protein, carotene, and riboflavin. Figure 18 shows a field of beets ready for harvesting. It produced about 7 tons of leaves per acre.

The variety and maturity of the plant, and the climatic conditions under which it is grown, greatly influence the chemical composition of beet leaf meal. Data obtained here on the Crosby Egyptian and the Detroit Dark Red varieties showed that the former yields a better quality leaf meal than the latter. Since the Detroit Dark Red variety is the one largely used for canning, however, it was used in most of these studies.

Table 7 shows the relative proportions of leaf, stem, and dirt fractions obtained by hand and by mechanical separation from typical field waste and the chemical analyses of the waste obtained in 1943 and 1944.

The leaf blade constitutes up to 53 percent of the whole waste on the fresh basis, and the trommel leaf meal constitutes up to 69 percent on the dry basis. The meals have an average content of about 25 percent protein, 7 percent crude fiber, 6 percent ether extract, and from 200 to 500 μg (micrograms) of carotene and from 13 to 26 μg of riboflavin per gram.

Since the stems contain as much as 13 percent protein and only 15 percent crude fiber, with a fairly high percentage of carotene and riboflavin, they would appear to be as valuable nutritionally as the alfalfa meal of 13 percent protein now commonly sold on the market. Separa-

FIGURE 18.—Beets ready for harvesting.

tion into leaf and stem meal would depend on economic conditions and on finding a market which might use products of this type.

BROCCOLI

Although broccoli is not a major crop, the waste from this vegetable is of considerable interest because of its exceptional quality, as shown by its chemical composition and feed value. No other vegetable leaf tissue has been found which contains as much protein, carotene, and riboflavin.

The waste from broccoli-processing plants is somewhat variable in composition, since there does not seem to be a standard practice in marketing or packing broccoli heads. In the first cutting of the large center heads, the waste consists of the lower end of the heavy stem, with or without attached leaves, and the leaves pulled from the stem near the head. Some time after the cutting of the large center head, the lateral shoots are harvested, and these provide a waste containing lighter stem pieces and more leaves. Since no attempt was made to differentiate between the two types of waste, the material obtained from the belt at the packing plant was usually a mixture of both types, especially in late summer and fall (fig. 19).

TABLE 7.—*Analyses of beet tops*

Material	Date harvested	Moisture	Proportion of whole top		Chemical analyses (moisture-free basis)				
			Fresh basis	Dry basis	Protein	Crude fiber	Ether extract	Carotene	Riboflavin
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*
Whole tops (field waste)	July 10, 1943	90.7	--------	--------	18.9	9.3	--------	203	14.7
Leaves and stems in good condition		--------	91.6	--------	--------	--------	--------	--------	--------
Weeds and dirt, dead leaves and stems		--------	9.4	--------	--------	--------	--------	--------	--------
Hand-separated leaves		90.4	52.6	54.2	27.3	6.0	6.2	568	21.5
Hand-separated stems		91.0	47.4	45.0	13.6	14.7	--------	48	7.4
Trommel leaf meal (from dirt-free leaves and stems)		--------	--------	68.8	23.7	7.1	--------	397	18.5
Trommel residue		--------	--------	31.2	--------	--------	--------	--------	--------
Trommel leaf meal	Oct. 30, 1943	--------	--------	--------	23.6	9.1	--------	208	12.9
Hand-separated leaves	June 29, 1944	--------	--------	--------	26.8	6.6	8.9	506	26.4
Trommel leaf meal		--------	--------	--------	25.8	7.1	7.0	417	24.9
Whole top	July 10, 1944	88.6	--------	--------	--------	--------	--------	--------	--------
Hand-separated leaves		--------	--------	--------	27.6	5.7	8.4	473	24.8
Trommel leaf meal		--------	--------	66.0	24.0	6.6	7.7	400	23.4
Trommel residue		--------	--------	27.0	--------	--------	--------	--------	--------
Screened stems and dirt		--------	--------	7.0	--------	--------	--------	--------	--------
Screened stems		--------	--------	--------	12.3	14.1	1.7	65	9.5
Whole top	Oct. 10, 1944	91.5	--------	--------	--------	--------	--------	--------	--------
Trommel leaf meal		--------	--------	66.3	26.8	5.2	4.2	438	14.7
Trommel residue		--------	--------	27.6	--------	--------	--------	--------	--------
Screened stems and dirt		--------	--------	6.1	--------	--------	--------	--------	--------

FIGURE 19.—Waste broccoli leaves coming off the sorting belt.

Table 8 shows the relative proportions of heavy stem pieces and leaves with petioles. It also shows the relative proportions of leaves and stems plus petioles for hand-separated and for trommel-separated material (meal and residue). The chemical composition of some of the preparations is also shown.

With an average of about 36 percent protein and from 500 to 800 μg of carotene and from 24 to 30 μg of riboflavin per gram, broccoli leaf meal is the most concentrated natural source of these nutrients found thus far. Since the proportion of stems or residue is from 30 to 50 percent of the whole dry weight and since they have protein and vitamin values equal to or greater than the alfalfa meal commonly available, the residue from the preparation of the leaf meal should have some value. The fractional drying and screening procedure is

TABLE 8.—*Analyses of broccoli waste*

Material	Date harvested	Moisture	Proportion of whole waste		Chemical analyses (moisture-free basis)				
			Fresh basis	Dry basis	Protein	Crude fiber	Ether extract	Carotene	Riboflavin
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*
Whole waste	Aug. 12, 1943	87.3							
Heavy stems			31.5						
Leaves and petioles			68.5						
Whole waste	Aug. 13, 1943	87.8							
Hand-separated leaves		84.8	49.2	61.4					
Hand-separated stems and petioles		90.7	50.9	38.6					
Trommel leaf meal				55.3					
Trommel residue				44.7					
Whole waste	July 28, 1944	87.5							
Hand-separated leaves		81.5	36.4	53.7	35.9	7.6	8.5	803	25.6
Hand-separated stems and petioles		91.0	63.6	46.3					
Trommel leaf meal				63.2	35.6	8.7	8.0	749	29.4
Trommel residue				36.8	22.4	20.6	2.3	81	7.7
Whole waste	Aug. 17, 1944	86.8							
Hand-separated leaves		81.8	34.2	47.2	36.2	7.4	8.5	741	27.1
Hand-separated stems and petioles		89.3	66.0	52.9					
Trommel leaf meal					37.1	8.0	10.3	622	25.6

necessary because of the slow drying of the large stem pieces, but complete drying of the residue after some mechanical disintegration might be worth while.

Broccoli is considered to be a cool-weather crop, and heads do not develop as well during hot weather (*40*). The strain of Calabrese broccoli used by the farms from which this material was obtained, however, seems to withstand the summer heat fairly well. The hot dry weather of July and August 1944 produced the source of the richest leaf meal. Table 9 shows that there were high concentrations of protein and vitamins in this broccoli. The too rapid maturing from August 4 to 8 was undesirable for the broccoli heads, but the leaves abounded in protein, carotene, and riboflavin.

Table 9 shows a trend toward lower values in plants that matured in the fall, but variations in the leaf meals prohibit the use of a curve to indicate this trend. The average daily period of sunlight in July 1944 was 11.5 hours, whereas in October it was only 7 hours. Thus it is possible that periods of intense sunlight preceding harvesting are responsible for the extremely high quality of some leaf meals.

The fact that meals made from plants matured in early November have protein values as high as 34 percent and carotene values as high as 617 μg per gram is of real importance, since it means that a drying season could extend well beyond the normal alfalfa drying season and still produce a high-quality product.

In order to determine the possible value of broccoli as a secondary crop to keep a drier busy for a longer season, about one-fourth acre in Bucks County, Pa., was seeded September 4, 1944, with a spinach planter, at 3- to 6-inch spacings in rows 12 inches apart. Harvested in November with a mowing machine, it yielded 1 ton of dry material per acre (fig. 20). The trommel leaf meal constituted 61 percent of the total dry material and contained 26 percent protein, 7 percent fiber, and 372 μg of carotene and 17 μg of riboflavin per gram. The complete data are given in table 10.

TABLE 9.—*Seasonal variation in analyses of broccoli trommel leaf meal*

Date harvested	Analyses (moisture-free basis)				
	Protein	Crude fiber	Ether extract	Carotene	Riboflavin
1944	*Percent*	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*
July 21	33. 8	10. 2	7. 0	405	26. 2
July 28	36. 6	8. 6	8. 0	749	29. 4
Aug. 4	37. 0	7. 8	8. 3	755	25. 5
Aug. 8	39. 3	8. 3	8. 1	750	26. 3
Aug. 8 [1]	43. 9	8. 7	8. 5	810	30. 7
Aug. 17	37. 1	8. 0	10. 2	622	25. 6
Sept. 4	35. 9	8. 2	8. 9	535	21. 5
Oct. 12	36. 4	7. 4	6. 5	637	25. 2
Oct. 18	31. 2	9. 1	6. 1	481	21. 9
Oct. 24	32. 7	8. 7	7. 3	607	25. 4
Nov. 4	30. 4	9. 4	6. 0	396	22. 3
Nov. 8	32. 5	8. 4	7. 2	617	27. 9
Nov. 14	34. 5	7. 2	8. 5	556	28. 2

[1] Many overmature heads were removed by hand.

TABLE 10.—*Analyses of thickly seeded broccoli*

Material	Date harvested	Moisture	Proportion of whole top		Chemical analyses (moisture-free basis)				
			Fresh basis	Dry basis	Protein	Crude fiber	Ether extract	Carotene	Riboflavin
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*
Hand-harvested whole top	Nov. 8, 1944	86. 8	-------	-------	-------	-------	-------	-------	-------
Hand-separated stems and petioles		81. 8	66. 0	52. 9	-------	-------	-------	-------	-------
Hand-separated leaves		89. 3	34. 2	47. 2	32. 9	7. 3	6. 8	538	24. 2
Hand-separated stems		-------	-------	-------	19. 0	16. 5	3. 3	31	8. 5
Machine-harvested plant:									
Hand-separated leaves	Nov. 18, 1944	85. 7	56. 9	-------	-------	-------	-------	-------	-------
Hand-separated stems and petioles		88. 0	43. 2	-------	-------	-------	-------	-------	-------
Trommel leaf meal		-------	-------	61. 4	25. 9	7. 0	6. 3	372	16. 8
Trommel residue		-------	-------	38. 7	21. 3	16. 9	3. 4	43	7. 1

FIGURE 20.—Broccoli sowed on September 4 in Bucks County, Pa., and harvested with a mowing machine in November.

There were about equal amounts of leaf and stem, on the dry basis, for the plant cut by hand close to the ground. In the machine-mowed material, the proportion of leafy material was greater.

The protein and vitamin contents of the leaf meals were less from the plants harvested on November 18 than from those harvested on November 8. Apparently the maximum quality leaf meal cannot be obtained at the extreme end of the season.

These preliminary figures indicate that broccoli might be a useful secondary forage crop, if planted thickly and harvested before the heads appear.

CARROTS

Although carrot tops are a potentially large source of waste well adapted to the preparation of a vegetable leaf meal, there are practical difficulties in harvesting them in a way that will give a high-quality product. The bright-green tops on bunched carrots are rich in protein, carotene, and other nutritionally valuable constituents. Carrots topped in the field, however, are allowed to mature more than the bunched carrots, and these tops have a much higher percentage of dead tissue than the immature ones. Another reason for the poor quality of the field-cut tops is that they are contaminated with dirt. This is acquired when the carrots are harvested with a plow, and the tops are twisted off and dropped on the ground. Any soil incorporated into the fine leafy structure is difficult to remove. The method of harvesting suggested for beet and other leafy tops having rigid

TABLE 11.—*Analyses of carrot tops*

Material	Date harvested	Moisture	Proportion of whole top		Chemical analyses (moisture-free basis)				
			Fresh basis	Dry basis	Protein	Crude fiber	Ether extract	Carotene	Riboflavin
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*
Whole top	Aug. 20, 1943	80. 2			14. 4	12. 4		240	8. 3
Trommel leaf meal				62. 5	18. 0	9. 1	4. 0	274	9. 1
Trommel residue				37. 5	9. 8	16. 9		122	5. 8
Whole top	Aug. 21, 1943	83. 0			15. 5	9. 8		145	10. 2
Trommel leaf meal				54. 0	10. 3	18. 0		62	6. 0
Trommel residue				46. 0	17. 8	10. 0		164	
Trommel leaf meal	Oct. 2, 1943				13. 6	11. 6	4. 4	134	9. 2
Trommel leaf meal	Sept. 1, 1944								
Whole top	Sept. 5, 1944	68. 5			10. 3	13. 2	6. 8	109	6. 9
Trommel leaf meal				59. 0					
Trommel residue				27. 0					
Screened stems and dirt				14. 0					
Whole top	Oct. 11, 1944	79. 7			12. 5	11. 4	2. 5	167	8. 0
Trommel leaf meal				60. 6					
Trommel residue				29. 9					
Screened stems and dirt				9. 5					
Hand-separated leaves [1]	Mar. 27, 1945	79. 0	51. 2	65. 1	27. 9	10. 1	5. 6	295	15. 7
Hand-separated stems [1]		88. 1	48. 8	34. 9	11. 1	19. 3	5. 4	41	8. 1

[1] Samples prepared by W. T. Forsee, of the Everglades Experiment Station, Belle Glade, Fla.

stems—cutting with a mower—would prevent this difficulty. The extreme dryness of 1943 and 1944, when these studies were made, also contributed to the poor quality of the material.

Some separation of the heavier petioles and stems can be effected by trommeling and screening after fractional drying, but it is a less satisfactory separation than with other products. Table 11 gives data on carrots grown in the Middle Atlantic States and on hand-separated fractions obtained from the Everglades Experiment Station at Belle Glade, Fla.

Compared with beet tops and broccoli, carrot tops have a lower moisture content, and hence yield a larger percentage of dried product. The material from Florida had a higher protein content than that from the Middle Atlantic States, but from the meager data available it cannot be concluded whether this was due to fewer dead leaves, conditions of growth, variety, or other factors. Dry weather in the latter area in 1943 and 1944 could have been a factor. Even though the quality was not so high as may be expected in more favorable seasons, the carotene content of the leaf meal was sufficient to provide adequate vitamin A for good broiler growth, as pointed out in chapter 4. The leaf meal had a pleasing spicy aroma and a deep-green color, two factors which are important in a feed supplement.

KALE

Because of the high nutritive value of broccoli, kale, a member of the same species of the mustard family, was considered as another possible source of a high-grade leaf meal. Although there is some waste kale in packing houses, the actual waste product was not available for these experiments. The material used was grown near the Laboratory or was good-quality fresh-market kale.

The material grown near the Laboratory was harvested at different stages of growth. Table 12 shows that the plants harvested on November 1 were of somewhat lower nutritive value than those taken from the same field at an earlier date. This may have been due to a combination of insufficient fertilizer and an infestation of aphids, since the material showed considerable dead tissue and yellowing when it was finally harvested.

Kale is a high-protein, high-vitamin product which will bear further study. Eight tons of fresh kale to the acre is not uncommon.[6] Because of the high proportion of leaf, this product compares favorably with broccoli as a crop to be grown especially for a feed supplement. In many sections of the country, it can be produced earlier in the spring and later in the fall than most vegetables, making it a valuable crop for extending the drying season.

LIMA BEAN VINES

Next to pea vines, lima bean vines were the most abundant of the wastes investigated. They have the same advantage as pea vines in regard to accumulation at a central point in large volume. An additional advantage is that the viner separates the heavy roots and stems

[6] Personal communication from M. M. Parker of the Virginia Truck Experiment Station, Norfolk, Va.

TABLE 12.—*Analyses of kale*

Material	Date harvested	Moisture	Proportion of whole top		Chemical analyses (moisture-free basis)				
			Fresh basis	Dry basis	Protein	Crude fiber	Ether extract	Carotene	Riboflavin
	1944	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*
Whole top	Sept. 29	89. 5	--------	--------	26. 3	9. 1	6. 6	527	11. 8
Hand-separated leaves		--------	--------	--------	33. 4	7. 6	6. 2	797	18. 2
Hand-separated stems		--------	--------	--------	--------	--------	--------	70	--------
Whole top	Oct. 11	88. 0	--------	--------	--------	--------	--------	--------	--------
Hand-separated leaves		86. 0	59. 8	69. 6	30. 9	6. 6	7. 2	628	16. 6
Hand-separated stems		91. 0	40. 4	30. 3	24. 1	14. 8	3. 5	98	8. 5
Whole top	Nov. 1	87. 2	--------	--------	--------	--------	--------	--------	--------
Hand-separated leaves		85. 7	61. 7	68. 6	25. 8	6. 8	7. 2	348	15. 9
Hand-separated stems		89. 5	38. 3	31. 4	18. 7	14. 1	3. 1	41	13. 7
Whole top [1]	Dec. 19	79. 4	--------	--------	--------	--------	--------	--------	--------
Hand-separated leaves		77. 3	57. 5	63. 3	29. 4	7. 6	5. 8	340	21. 0
Hand-separated stems		82. 3	42. 5	36. 7	16. 2	10. 0	4. 2	21	8. 0
Trommel leaf meal		--------	--------	57. 0	27. 2	6. 6	7. 1	338	15. 3
Trommel residue		--------	--------	43. 0	16. 1	9. 9	3. 9	39	10. 6

[1] This material was grown, harvested, and shipped to the Laboratory by M. M. Parker, of the Virginia Truck Experiment Station, Norfolk, Va.

from the leaves, which are collected in the apron fraction. This is shown in figure 21.

Data were obtained on the hand-separated unvined whole plant and on the viner apron fraction (table 13) for comparison with data on the leaf meal and residue from the whole viner product and from the viner apron fraction (table 14). This comparison indicates the relative efficiency of the viner separation of the leaves and the separation by drying and trommeling. Because of the uneven distribution of the stems and leaves in the whole viner product, it was not possible to separate them by hand for analyses.

FIGURE 21.—Viner apron fraction of lima bean vines.

The extent of the separation and concentration of the leafy fraction of the lima bean vines by the viner can readily be seen in table 13. When the plant is pulled from the ground and separated by hand, about 15 percent is leaves, whereas the viner apron fraction has about 73 percent. Mechanical separation by fractional drying and trommeling produces a leaf meal fraction of from 31 to 42 percent for the whole viner product and 82 percent for the apron fraction (table 14). The chemical compositions of the leaf meals prepared from the whole viner product and from the apron fraction are approximately the same, but use of the apron fraction would be preferable, since a great deal less material would have to be dried to obtain the desired leaf meal.

One disadvantage of the apron fraction is the high proportion of dirt that it contains. This dirt probably accounts for the lower

TABLE 13.—*Analyses of lima bean vines*

Material	Date harvested	Moisture	Proportion of whole vine or fraction				Chemical analyses (moisture-free basis)				
			Fresh basis		Dry basis						
			With beans	Without beans	With beans	Without beans	Protein	Crude fiber	Ether extract	Carotene	Riboflavin
	1944	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*
Unvined:											
Whole plant [1]	Sept. 27	71. 6	-------	-------	-------	-------	-------	-------	-------	-------	-------
Leaves		67. 7	15. 8	20. 0	18. 0	25. 0	19. 4	10. 5	6. 4	465	12. 4
Stems		74. 3	36. 9	46. 7	33. 5	46. 6	9. 2	40. 1	2. 2	36	3. 9
Pods		77. 1	25. 8	32. 6	20. 9	29. 0	10. 0	37. 8	3. 0	14	3. 7
Beans		61. 6	20. 8	-------	28. 1	-------	23. 9	6. 0	3. 7	3	2. 4
Whole plant	Oct. 13	67. 9	-------	-------	-------	-------	-------	-------	-------	-------	-------
Leaves		67. 4	13. 9	19. 4	14. 2	20. 1	20. 9	10. 8	5. 2	440	13. 0
Stems		72. 5	34. 6	48. 5	29. 7	44. 3	7. 1	36. 6	2. 4	49	4. 6
Pods		67. 9	23. 0	32. 2	23. 1	34. 4	5. 0	44. 2	1. 0	18	3. 5
Beans		62. 8	28. 3	-------	32. 9	-------	20. 5	5. 8	4. 0	2	2. 6
Viner apron fraction:											
Whole fraction [2]	Oct. 13	68. 5	-------	-------	-------	-------	-------	-------	-------	-------	-------
Leaves		68. 1	72. 8	75. 9	73. 8	78. 6	14. 3	7. 6	4. 8	181	10. 2
Stems		73. 4	18. 1	18. 8	15. 3	16. 3	8. 4	28. 2	2. 6	67	6. 5
Pods		70. 4	5. 0	5. 2	4. 7	5. 0	6. 0	38. 4	1. 5	21	4. 3
Beans		53. 8	4. 2	-------	6. 1	-------	20. 2	5. 3	3. 1	2	3. 5

[1] Includes leaves, stems, pods, beans, and roots.
[2] Includes leaves, small stems, and a small proportion of pods and beans.

TABLE 14.—*Analyses of lima bean vine products*

Material	Date harvested	Moisture	Proportion of whole product or fraction (dry basis)	Chemical analyses (moisture-free basis)				
				Protein	Crude fiber	Ether extract	Carotene	Riboflavin
	1944	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Micrograms per gram*	*Micrgrams per gram*
Whole viner product	Sept. 11	71. 9						
Trommel leaf meal			41. 9	15. 2	14. 4	4. 8	266	10. 3
Trommel residue (stems, dirt, pods)			58. 1					
Whole viner product	Sept. 21	71. 5						
Trommel leaf meal			31. 0	14. 6	12. 0	4. 8	244	9. 6
Trommel residue (stems, dirt, pods)			69. 0	7. 7	34. 0	1. 9	40	4. 3
Viner apron fraction	Sept. 29	72. 0						
Trommel leaf meal			82. 0	13. 9	8. 5	4. 2	187	7. 6
Trommel residue (small stems, dirt)			18. 0					

protein values in the hand-separated leaves from the viner apron fraction, as compared with the hand-separated unvined leaf fraction. Screening the dried leaf fractions through a 60-mesh screen eliminates much of the dirt, but it cannot be removed completely, since it is actually beaten into the leaf tissue by the paddles of the viner. No type of separation thus far tried has completely removed it.

The lower carotene value of the hand-separated viner leaves, as compared with that of the unvined leaves, shown in table 13, cannot be wholly attributed to the dirt in the vined material. Preliminary experiments showed that loss of carotene is due either to enzymatic or oxidative destruction during the interval between vining the product and drying it at the Laboratory. Analysis of lima bean leaves preserved in alcohol as soon as they were removed from the viner showed that little loss of carotene occurred during the vining operation itself. That the bruising of the leaves, with subsequent standing even at cold storage temperatures, was the reason for the loss was shown by the fact that unvined leaves had 420 μg of carotene per gram at the viner and 444 μg 24 hours later at the Laboratory, identical values within the limits of experimental error, whereas vined leaves changed from 400 to 266 μg per gram during the same period.

Drying caused no further loss of carotene in the vined leaves. Pea vine experiments carried out at the viner with a portable high-velocity drier showed that carotene losses occurred in vined leaves during drying even when the leaves were dried immediately. Whether comparable losses occur in lima bean vines is not yet known. Because of the high dry weight of the apron fraction coupled with its high carotene and tocopherol contents (table 25), lima bean vines will be one of the best commercial prospects, if this fraction can be dried so that it retains its original carotene content.

PEA VINES

Since pea vines constitute one of the main vegetable wastes in many sections of the country and since they accumulate in huge piles at the viners (fig. 22), their chemical composition has been given considerable attention. The information is still not complete and applies only to those grown in the vicinity of the Laboratory, but it is believed that the data given here are sufficient to enable the grower and processor to determine how they can use the great amount of raw material which they now possess. The experiments on pea vines began with commercial drying studies in 1941 and continued through the 1945 season. A few data on chemical composition were obtained before 1943. These, together with the complete data of 1943 and 1944 and some additional data obtained in 1945, constitute most of the information on pea vines.

The commercial drying studies of 1941 and 1942 showed that the alfalfa driers used were not entirely suitable for drying pea vines,

either because the pods were not dried sufficiently in a rapid-type drier and caused spoilage or because prohibitive loss of carotene occurred in other parts of the vined material when drying was continued long enough to dry the pods completely. Loss of nutritive value also occurred if the vines were allowed to heat between vining and drying.

Table 15 gives some of the data obtained in 1943; these are supplemented by data on the screened material in table 16. Table 17 contains the more complete data obtained in 1944. Hand-separated fractions of the unvined and the vined material are compared in this

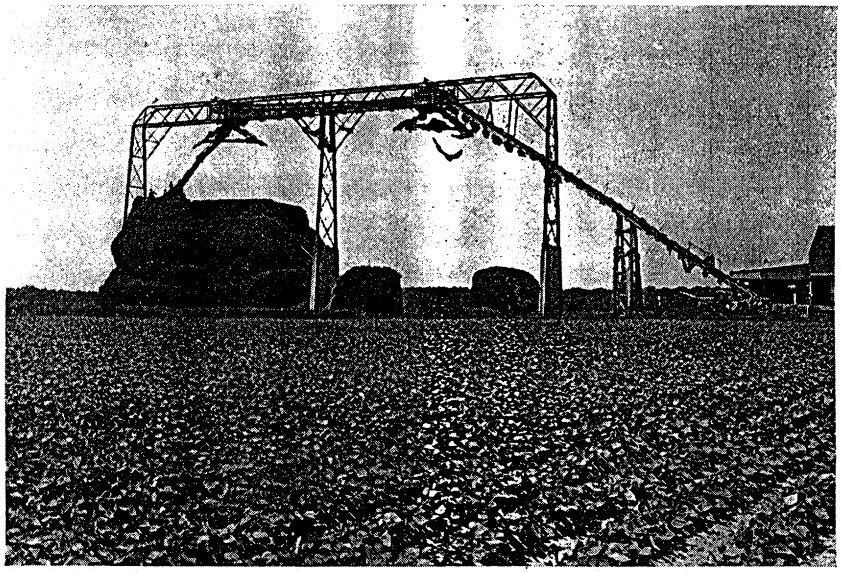


FIGURE 22.—The beginning of a pile of 2,000 tons of pea vines at a viner station.

table. Table 18 gives data for four pilot-plant runs on pea vines in 1944. Table 19 gives the analyses of the products.

In order to determine where loss of carotene occurs, in 1945 a small portable drier was set up at the viner for drying the vines as they came through. Samples were also brought to the Laboratory for analysis. Some were preserved in alcohol or in a Dry Ice storage box for analysis in the undried condition; others were kept for various periods in cold storage and then dried and analyzed. Table 20 shows the carotene contents of fresh and of dried samples, and the protein, crude fiber, ether extract, and riboflavin values of the dried samples.

Table 17 shows that the leaves constitute only about 12 percent of the total weight of the unvined plant on the fresh basis and 14 per-

TABLE 15.—*Analyses of pea vine* [1] *products prepared in 1943*

Sample No.	Material	Moisture	Analyses (moisture-free basis)			
			Protein	Crude fiber	Carotene	Riboflavin
		Percent	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*
1	Whole viner product; dried in special rotary drier; ground in ¼-inch hammer mill; −20 +30 mesh fraction (50 percent of whole dried product); slightly scorched	6. 5	18. 4	17. 7	[2] 31. 0	[2] 16. 0
2	Whole viner product; dried in tray drier; ground; not separated	4. 9	12. 9	26. 1	59. 5	11. 0
3	Apron fraction from viner; dried in tray drier	5. 1	18. 4	15. 4	62. 0	15. 4
4	Whole plant (without peas); dried in tray drier	6. 2	14. 1	29. 6	72. 0	9. 7
5	Hand-stripped leaves from sample 4; dried in tray drier	4. 1	24. 8	11. 7	179. 5	25. 8
6	Pea pods from sample 4; dried in tray drier	6. 6	14. 9	22. 9	50. 0	9. 3
7	Peas from sample 4; dried in tray drier	6. 5	26. 9	11. 8	52. 0	5. 7
8	Pea vine silage; dried in tray drier:					
	Ground to −30 mesh (34 percent)	2. 7	12. 3	21. 2	107. 8	6. 3
	Ground to −20 +30 mesh (16 percent)	2. 9	10. 0	33. 3	60. 2	6. 7
	Ground to +20 mesh (50 percent)	2. 9	8. 2	41. 7	31. 8	5. 9

[1] A strain of Thomas Laxton variety.
[2] After 2 months' storage at room temperature. The initial value was 90 micrograms per gram.

TABLE 16.—*Analyses of pea vine products separated by screening*

Load No.	Date obtained	Material	Size of screen	Proportion of product	Chemical analyses			
					Protein	Crude fiber	Carotene	Riboflavin
	1943		*Mesh*	*Percent*	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*
1	June 18	Whole viner product [1]			14.0		52	
		Viner apron fraction [1]; dried in tray drier			18.5		62	
2	June 22	Whole viner product [1]; dried in rotary drier; ground in 1/16-inch hammer mill	+20	50	11.1	38.9	59	
			+30		14.7	29.6	77	
			+40	50	16.5	23.7	128	
3	June 24		+60		19.1	18.1	178	16.5
			+80		20.6	17.2	180	16.5
			−80		19.3	15.1	187	
4	June 30	Whole viner product [2]; dried in rotary drier; ground in 1/4-inch hammer mill	+20	60	11.4	38.4	44	
			+40	40	17.8	21.0	88	12.7
			−40		19.8	14.3	118	
		Whole viner product [2]; sun-dried; ground in 1/4-inch hammer mill	−40		19.4	15.9	28	13.5

[1] A strain of Thomas Laxton variety.
[2] Alderman variety.

TABLE 17.—*Analyses of vined and unvined pea vines* [1] *harvested in 1944*

Material	Moisture	Proportion of whole vine				Chemical analyses (moisture-free basis)				
		Fresh basis		Dry basis						
		With peas	Without peas	With peas	Without peas	Protein	Crude fiber	Ether extract	Carotene	Riboflavin
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*
Unvined; separated by hand:										
Whole plant	75. 9									
Leaves	65. 7	12. 3	15. 8	14. 1	17. 5	21. 7	14. 4	5. 8	346	26. 2
Pods	84. 0	35. 5	45. 8	25. 2	31. 3	14. 1	18. 4	1. 2	23	7. 8
Stems	67. 4	29. 9	38. 5	41. 0	51. 0	11. 0	39. 2	2. 3	47	9. 6
Peas	80. 1	22. 4		19. 9		28. 8	9. 2	1. 7	4	7. 8
Vined; separated by hand:										
Whole viner fraction	68. 2									
Leaves	64. 0	15. 1		16. 4		22. 2	12. 2	4. 4	276	23. 6
Pods	78. 5	34. 6		24. 6		15. 4	17. 1	1. 0	14	9. 3
Stems	62. 5	50. 1		59. 0		12. 0	36. 6	2. 0	46	10. 4
Unvined (minus peas); not separated	75. 3					14. 2	25. 8	2. 6	132	15. 4
Vined; not separated	73. 9					14. 2	27. 0	2. 6	76	13. 8

[1] A strain of Thomas Laxton variety.

TABLE 18.—*Data on pea vines dried in the pilot plant in 1944*

Load No.	Weight	Date obtained	Weather	Moisture	Time in tray drier at 240° F.	Yield	
						Trommel leaf meal	Screened leaf meal [1]
	Pounds			*Percent*	*Minutes*	*Percent*	*Percent*
1	2, 230	June 14, 8:30 a. m.	June 1–14, 0.3-inch rainfall	75. 2	40 (for trommeling)	8. 7	--------
2	3, 190	June 15, 2:30 p. m.	June 14–15, 0.65-inch rainfall	83. 8	40 for trommeling 60 for complete drying	5. 1 --------	-------- 7. 5
3	3, 020	June 19, 9:00 a. m.	June 15–18, clear June 19, 1.93-inch rainfall	84. 4	50 for trommeling 90 for complete drying	7. 3 --------	-------- 7. 5
4	2, 770	June 22, 11:00 a. m.	June 19–20, 2.05-inch rainfall June 21, cloudy June 22, clear	81. 5	240° for 30 min., then 160° for 30 min. (for complete drying).	--------	9. 3

[1] Ground in ¼-inch hammer mill to −20 mesh.

TABLE 19.—*Analyses of pea vine products dried in the pilot plant in 1944* [1]

Load No.	Material	Moisture	Protein	Crude fiber	Ether extract	Carotene	Riboflavin
		Percent	*Percent*	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*
1	Trommel leaf meal	9. 5	15. 3	15. 7	3. 6	73. 4	15. 5
	Trommel residue (dried)	7. 9	9. 8	28. 4	1. 1	34. 7	9. 0
2	Trommel leaf meal	6. 6	10. 9	25. 4	2. 6	55. 0	13. 6
	Trommel residue (dried)	5. 0	8. 9	32. 5	1. 8	26. 0	10. 0
	Completely dried and ground to −20 mesh	9. 2	11. 2	20. 0	2. 7	50. 9	14. 5
	Completely dried and ground to +20 mesh	8. 8	7. 5	39. 4	1. 8	23. 7	9. 0
3	Trommel leaf meal	5. 0	13. 5	20. 5	3. 2	100. 2	15. 8
	Trommel residue (dried)	5. 5	9. 7	32. 3	1. 9	34. 3	8. 9
	Completely dried and ground to −20 mesh	7. 2	13. 8	18. 2	2. 7	79. 8	16. 5
	Completely dried and ground to +20 mesh	10. 7	9. 6	33. 1	1. 9	27. 8	10. 2
4	Completely dried and ground to −20 mesh	6. 7	15. 4	19. 3	5. 4	90. 6	17. 1
	Completely dried and ground to +20 mesh	7. 5	9. 8	35. 1	3. 5	28. 1	9. 0

[1] Data on drying given in table 18.

cent on the dry basis. Without the peas, these proportions are about 16 and 17 percent, respectively. The leaves of the vined material are about 15 percent of the fresh weight and 16 percent of the dry weight. Table 17 also shows that in protein, carotene, and riboflavin contents the leaves alone are comparable with the leaves of the other vegetables studied but that the stems and pods, which constitute about 84 percent of the total weight (fresh basis), are of lower quality. The preparation of a leaf meal concentrate from pea vines would mean, therefore, that either a great deal of material would have to be processed to obtain the small fraction of rich leaves or a meal of lower nutritive value and higher fiber content would be produced.

Since, unlike lima bean leaves, pea leaves are not separated from the stems and pods by the viners, it is not possible to process the apron fraction alone for a better quality leaf meal. The apron fraction is of fair quality, as shown in table 15, but the proportion is so small that it would not be significant in the utilization of pea vines.

The whole dried product would be satisfactory for cattle feed or other cheap feed, but for a poultry feed supplement it would be necessary to grind and screen this material to obtain a less fibrous, more concentrated meal.

Table 16 shows the effect of screening through different meshes on the chemical composition of the 1/16- and 1/4-inch hammer-milled products. A maximum of 20.6 percent protein was obtained from the +80-mesh fraction of the 1/16-inch grind and 19.8 from the −40-mesh fraction of the 1/4-inch grind. Since the quantity of leaf that passed these finer screens was extremely small, it was necessary to compromise between yield and quality. The −20 +30-mesh fraction, which represented 50 percent of the whole dried product and had 18.4 percent

TABLE 20—*Analyses of pea vine products prepared in 1945*

Sample No.	Material	Date harvested	Protein [1]	Crude fiber [1]	Ether extract [1]	Carotene		Riboflavin [1]
						Fresh material [2]	Dried material [3]	
		1945	*Percent*	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*	*Micrograms per gram*
1	Unvined, hand-separated leaves; preserved in alcohol	June 6	-------	-------	-------	450	-------	-------
2	Unvined, hand-separated leaves; after 20 hours on Dry Ice	June 6	-------	-------	-------	460	327	-------
3	Vined, hand-separated leaves; preserved in alcohol	June 6	-------	-------	-------	359	-------	-------
4	Vined, hand-separated leaves; after 20 hours on Dry Ice	June 6	25. 4	11. 2	6. 0	337	271	18. 3
1	Vined, hand-separated leaves; dried immediately at viner	June 15	-------	-------	-------	440	286	-------
2	Whole viner product; dried immediately at viner	June 15	11. 6	33. 0	5. 2	-------	68	10. 4
3	Whole viner product; dried after 20 hours at 40° F.	June 15	15. 3	12. 6	2. 5	-------	78	10. 8
4	Whole viner product; dried immediately at viner; ground to −30 mesh	June 15	14. 0	24. 5	3. 6	-------	86	12. 9
5	Whole viner product; dried after 20 hours at 40° F.; ground to −30 mesh	June 15	18. 0	21. 8	3. 5	-------	96	13. 7
6	Whole viner product; dried immediately at viner; ground to +30 mesh	June 15	8. 5	40. 3	3. 1	-------	31	6. 5
7	Whole viner product; dried after 20 hours at 40° F.; ground to +30 mesh	June 15	11. 3	38. 0	3. 1	-------	30	9. 1

[1] Moisture-free basis.
[2] Calculated to basis of 5 percent moisture.
[3] Dried to approximately 5 percent moisture.

TABLE 20—*Analyses of pea vine products prepared in 1945*—Continued

Sample No.	Material	Date harvested	Protein [1]	Crude fiber [1]	Ether extract [1]	Carotene		Riboflavin [1]
						Fresh material [2]	Dried material [3]	
		1945	*Percent*	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*	*Micrograms per gram*
1	Unvined, hand-separated leaves; dried immediately at viner	June 25	25. 9	10. 2	10. 8	433	355	21. 4
2	Vined, hand-separated leaves, dried immediately at viner		24. 0	11. 8	9. 3	457	292	20. 3
3	Whole viner product; dried immediately at viner		10. 6	37. 0	6. 0	----------	40	8. 3
4	Whole viner product; dried after 42 hours at 40° F.		14. 4	28. 3	8. 0	----------	93	14. 3
5	Whole viner product; dried immediately at viner; ground to −35 mesh		12. 8	29. 4	5. 5	----------	52	9. 9
6	Whole viner product; dried immediately at viner; ground to +35 mesh		7. 0	49. 1	2. 9	----------	18	3. 2
7	Whole viner product; dried after 42 hours at 40° F.; ground to −35 mesh		16. 0	25. 6	7. 4	----------	108	14. 9
8	Whole viner product; dried after 42 hours at 40° F.; ground to +35 mesh		9. 4	40. 5	4. 7	----------	26	6. 9

[1] Moisture-free basis.
[2] Calculated to basis of 5 percent moisture.
[3] Dried to approximately 5 percent moisture.

protein and 17.7 percent fiber, as shown in table 15, was selected as the most desirable. The carotene content of this particular preparation was low because during the early experimental screening work the material was allowed to stand for some time at high summer temperatures. The initial carotene value of this meal was 90 μg per gram.

Tables 18 and 19 give the results of the 1944 pilot-plant drying and screening experiments. All the vines were obtained from one of the viners at a commercial truck farm in this vicinity. The first load consisted of the output from the end of the No. 1 viner unit plus the apron fractions from the other units. The viner end fraction, which constituted the greater part of the material, consists of stems with attached leaves and pods. The small apron fraction consists of broken leaf pieces, small stem pieces, and pods mixed with some peas and dirt. The remaining three loads were all viner end fractions. Weather data were included in this experiment to show how much the yield of meal was influenced by the amount of rain that preceded harvesting. These experiments showed that there was no advantage in the fractional drying procedure, either in quality of product or yield, as compared with drying the whole product.

As shown in table 19, the ¼-inch hammer-milled product screened through the 20-mesh screen was lower in protein content than the meal prepared in 1943 (table 15), 15.4 percent being the highest value obtained in the 1944 experiments. It is apparent that seasonal variation in protein content can be expected. The crude fiber and carotene contents were about the same as in the 1943 preparations, ranging from 18 to 20 percent of crude fiber and from 15 to 91 μg per gram of carotene in the −20-mesh fraction of the completely dried product.

Table 20 shows that carotene was lost in drying both the unvined and the vined leaves. The fresh, hand-separated, unvined leaves collected on June 6, 1945, and preserved in alcohol had 450 μg of carotene per gram; after the material was kept on Dry Ice for 20 hours the value was 460; when it was then dried the value was 327. Fresh vined leaves collected the same day had 359 μg per gram. After 20 hours in a Dry Ice refrigerator, the vined material had 337 μg per gram, and when then dried, 271. These values show that vining resulted in a loss of carotene and that drying caused still further loss. In the material obtained on June 25, however, vining caused no loss of carotene, but the loss caused by drying was greater in the vined material than in the unvined. This lack of agreement with results of June 6 was probably due to sampling error, since some leaves are bruised more than others in the viner.

The −30-mesh fraction of the whole viner product dried immediately at the viner had approximately the same carotene content as material brought to the Laboratory and kept in cold storage for 20 hours before drying. These results varied because of sampling error, since only 2 pounds of material was dried at one time (the capacity of the portable drier). This is particularly noticeable in the samples obtained on June 25, in which the −35-mesh fraction of the product dried immediately at the viner had a carotene value of only 52 μg per gram, as compared with 108 in the −35-mesh fraction of the product dried after 42 hours' cold storage.

The analyses of the dried products given in table 20 are consistent with the results obtained in 1943 and 1944 and show again that pro-

tein values for hand-separated leaves average about 25 percent but the values of the best leaf meals range from 14 to 18 percent.

TURNIPS AND RUTABAGAS

Turnip and rutabaga wastes were investigated to determine their possible value as early and late crops for use in a drier set up for general vegetable wastes. The volume of these wastes is not great, but since their nutritive value is high they could easily find a place in a program of vegetable waste utilization. Protein values of about 31 percent, carotene values of 473 μg per gram for turnip and 257 for rutabaga waste, and riboflavin values of about 20 μg per gram bring both products into the top group of highly nutritive vegetable wastes.

Table 21 shows representative weight and chemical data for turnip tops and for rutabaga tops.

RHUBARB

Rhubarb waste was investigated because of its ready availability and its unusual chemical composition. In normal times a considerable amount of this waste is available in the East at the fresh-market packing houses. It is one of the cleanest and most nearly pure leaf wastes studied in this investigation, since the petiole, which usually accompanies other leafy wastes, is the marketable portion. The veins are the only nongreen leafy tissue, and these can easily be separated by the fractional drying method. Table 21 shows the proportion and analyses of trommel leaf meal prepared from this waste.

Of all the vegetable products studied, only rhubarb leaf showed extensive destruction of chlorophyll during drying. While the material was being dried, the bright-green chlorophyll of the fresh leaf changed rapidly to greenish-brown pheophytin. No corresponding loss of carotene or tocopherol occurred during drying.

It is probable that this destruction of chlorophyll is due to the high organic acid content of the rhubarb leaf. The oxalic acid content of this material is 4.2 percent of the dry weight. However, no corresponding loss of chlorophyll occurs in beet leaves, which have more than twice as much oxalic acid as the rhubarb leaf. Winton (*50*) states that malic acid is present in the rhubarb petiole in even greater concentration than oxalic acid. If this acid is also in the leaf, it may be partly responsible for the break-down of chlorophyll.

Rhubarb leaf meal compares favorably with beet, broccoli, turnip, and other high-grade leaf meals in protein, carotene, and riboflavin (table 21), but owing to its brown color it probably would not be so acceptable as a feed supplement as some of the greener meals. Because of its high tocopherol content, it would probably be excellent as a source of lipidal constituents.

SPINACH

Relatively little work has been done on spinach waste, since it occurs mostly at canneries or freezing plants. The problem of handling the wet and bruised residues from trimming operations has not been satisfactorily worked out as yet.

TABLE 21.—*Analyses of turnip tops, rutabaga tops, rhubarb leaves, and wintered-over spinach*

Material	Date harvested	Moisture	Proportion of whole waste		Chemical analyses (moisture-free basis)				
			Fresh basis	Dry basis	Protein	Crude fiber	Ether extract	Carotene	Riboflavin
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*
TURNIP TOPS									
Whole top	July 7, 1943	90.4	-------	-------	22.5	8.3	-------	176	-------
Hand-separated leaves	July 7, 1943	87.3	46.8	61.9	30.9	7.5	4.4	473	20.3
Hand-separated stems	July 7, 1943	93.1	53.2	38.2	18.0	10.3	-------	54	11.6
Whole top	Aug. 20, 1943	91.6	-------	-------	-------	-------	-------	-------	-------
Trommel leaf meal	Aug. 20, 1943	-------	-------	57.4	29.0	8.3	-------	396	20.5
Trommel residue	Aug. 20, 1943	-------	-------	42.6	-------	-------	-------	-------	-------
RUTABAGA TOPS									
Whole top	Nov. 1943	87.5	-------	-------	-------	-------	-------	-------	-------
Hand-separated leaves	Nov. 1943	82.2	36.1	51.4	31.5	6.3	6.5	257	20.9
Hand-separated stems	Nov. 1943	90.5	63.6	48.4	18.5	14.9	-------	13	8.5
RHUBARB LEAVES									
Whole waste	July 19, 1944	90.4	-------	-------	-------	-------	-------	-------	-------
Trommel leaf meal	July 19, 1944	-------	-------	77.7	26.9	9.1	6.5	521	20.8
Trommel residue	July 19, 1944	-------	-------	22.2	-------	-------	-------	-------	-------
WINTERED-OVER SPINACH									
Whole waste	May 19, 1944	92.1	-------	-------	30.4	6.3	-------	272	13.3
Hand-separated leaves	May 19, 1944	90.4	45.1	54.7	32.0	6.8	4.1	314	14.6
Hand-separated stems	May 19, 1944	93.5	55.0	45.3	22.5	9.3	-------	120	8.5
Whole waste	May 20, 1944	90.9	-------	-------	-------	-------	-------	-------	-------
Trommel leaf meal	May 20, 1944	-------	-------	69.4	30.9	9.6	5.4	402	26.8
Trommel residue	May 20, 1944	-------	-------	30.6	-------	-------	-------	-------	-------

One source of high-quality field waste often available in this vicinity during late spring is fall-planted or wintered-over spinach. It is available as a waste either because of unfavorable marketing conditions or because early hot weather causes the crop to go to seed before it can be marketed (fig. 23). Frequently many hundreds of acres of this lush crop are plowed under.

FIGURE 23.—Wintered-over spinach which has become too old for market but is still rich in protein and vitamins.

This type of spinach would easily lend itself to mechanical harvesting, since it grows considerably higher than spring spinach and has a rigid though tender stalk, against which a cutter could work easily. The cut waste could be readily processed by fractional drying and separating.

Table 21 shows the average moisture content of this material, the proportion of leaf and stem, and its analyses.

Spinach is one of the three products studied in this work that contain appreciable amounts of oxalic acid. The leaf meal from the wintered-over material studied contained 3.5 percent. Chicks fed up to 5 percent of this meal in the normal ration, however, grew well and showed no harmful effects. This is in agreement with the observations of Remington and Smith (*33*), who found no harmful effects on rats fed even larger amounts of dried spinach in a diet adequate in calcium.

The leaf meal prepared from wintered-over spinach was the greenest meal obtained so far, and this fact, together with a protein value of about 31 percent, a carotene value of 402 μg per gram, and a ribo-

flavin value of 27 μg per gram, should make this a most acceptable feed supplement. Spinach leaf meal has a nutrient value second only to that of broccoli.

CELERY

Celery waste occurs in large enough volume in certain sections to warrant its inclusion in a study of vegetable wastes as feed supplements. Celery-packing operations in the Everglades section of Florida[7] produce several types of waste. There is a preliminary stripping of leaves and stalks in the field as the celery is cut for field boxing. After it is boxed, the tops are cut even with the top of the box, giving a fraction called clippings, which is largely leafy. At the packing house, additional stalks and a small quantity of leaves are stripped off. The strippings taken for analysis were separated into leaves and stalks by hand both in the field and at the packing house.

Samples of the various products were dried in a small continuous-circulation drier. Table 22 gives their analyses.

TABLE 22.—*Analyses of celery waste*

Material	Moisture	Analyses (moisture-free basis)				
		Protein	Crude fiber	Ether extract	Carotene	Riboflavin
	Percent	*Percent*	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*
Leaves (field)	87.0	27.2	3.5	6.9	352	18.4
Stalks (field)	94.0	12.6	14.3	3.1	11	5.7
Crate clippings	88.0	29.6	9.9	6.6	315	19.9
Leaves (packing house)	89.3	28.8	10.7	6.7	284	15.4
Stalks (packing house)	94.3	11.8	14.8	3.7	10	7.4

The celery waste from a cannery in the vicinity of Philadelphia was studied briefly. This material, which consisted of the leaves and stalks discarded at the sorting belt, had had considerable washing and handling and was badly bruised. Sufficient time had elapsed from its original cutting in the South to cause a heavy loss of carotene.

A fairly large batch was dried by the fractional drying procedure. The leaf meal obtained had the following composition: Protein, 31 percent; crude fiber, 11 percent; ether extract, 3.2 percent; carotene, 78 μg per gram. These figures indicate that a high-protein leaf meal could be obtained by the large-scale fractional drying procedure and that freshly gathered material would probably give a meal of high vitamin content.

Because of its high content of protein and vitamins and low content of crude fiber, celery leaf meal should make a good poultry feed supplement. Since the whole waste contains a considerable volume of leaves, the whole dried product should be acceptable as a stock feed.

[7] Most of the material used for this investigation was obtained through the cooperation of the Everglades Experiment Station, Belle Glade, Fla. The samples were collected and dried by W. T. Forsee, Jr., of the Everglades Experiment Station. The moisture contents of the various fractions are based on his figures.

MISCELLANEOUS WASTES

Vegetable wastes other than those mentioned have been studied, but insufficient data have been collected to warrant a discussion of each. Table 23 gives the analyses of some of the wastes which might be used with other wastes in a program of vegetable waste utilization.

TABLE 23.—*Analyses of miscellaneous vegetable wastes*

Material	Analyses (moisture-free basis)				
	Protein	Crude fiber	Ether extract	Carotene	Riboflavin
	Percent	*Percent*	*Percent*	*Micrograms per gram*	*Micrograms per gram*
Cabbage leaves (Savoy)	22.4	8.2	4.7	[1] 295	9.9
Cauliflower leaves	26.6	9.5	4.1	[2] 185	23.2
Cauliflower petioles	17.1	17.3	------	28	9.2
Collard leaves	27.3	6.8	5.3	251	15.8
Collard petioles	14.8	9.8	------	28	--------
Sweet corn leaves	17.1	26.6	5.5	578	5.5
Parsnip leaves	22.9	8.0	5.0	[3] 232	11.9
Parsnip stems	6.0	17.2	------	4	4.3

[1] After 3 months' storage.
[2] After 4 months' storage.
[3] After 5 months' storage.

OXALIC ACID AND TOCOPHEROL CONTENTS OF LEAF MEALS

In addition to the chemical constituents discussed, two other substances in leaf meals—oxalic acid and tocopherol—have been investigated because of special interest regarding their role in feeding or their effect on the meal during storage.

Oxalic acid is present in certain plant tissues in considerable amounts (*34*). Some of the vegetable leaf meals were analyzed for this acid by the method of Pucher, Vickery, and Wakeman (*31*). Table 24 shows the results.

TABLE 24.—*Oxalic acid content of various vegetable leaf meals*

Vegetable leaf meal	Oxalates as oxalic acid	Vegetable leaf meal	Oxalates as oxalic acid
	Percent		*Percent*
Beet	12.2	Lima bean	0.72
Broccoli	.16	Rhubarb	4.20
Carrot	.52	Spinach	3.52

Three of the leaf meals studied—beet, rhubarb, and spinach—have high oxalic acid contents, but they do not have harmful effects when fed to chicks, as shown by feeding tests (chap. 4). The results of these tests are consistent with the recent work of Remington and Smith with spinach (*33*). Storage studies indicate that oxalic acid may even have some beneficial effect in preventing loss of carotene in stored leaf meals.

Tocopherol, vitamin E (chap. 5), has been known for some time as a constituent of certain germ oils, but it has been determined in plant tissue in only a few instances (*18*, *36*, *37*). Much work has been done on the vitamin activity of α-tocopherol and a limited amount on its antioxidant activity (*12*).

Table 25 shows the tocopherol value of a number of leaf meals and vegetables. These values were determined by the Fürter-Meyer and Emmerie-Engel methods, as modified by Wall and Kelley (*45*). Since many of the leaf meals contain relatively large amounts of tocopherol, they should be excellent sources of this substance, for use either as an antioxidant to prevent loss of carotene during assimilation or to satisfy vitamin E requirements in poultry and animal rations.

TABLE 25.—*Tocopherol content of various vegetable tissues and feed materials determined by the Fürter-Meyer and the Emmerie-Engel procedures*

Material	Tocopherol determined by—	
	Fürter-Meyer procedure	Emmerie-Engel procedure
	Milligrams per gram	*Milligrams per gram*
Alfalfa meal	0.23	0.26
Beet leaf meal	.44	.71
Broccoli leaf meal	.39	.42
Kale leaf meal	.36	.39
Lima bean leaf meal	.72	.70
Rhubarb leaf meal	1.24	1.20
Spinach leaf meal	.42	.40
Turnip top meal	.34	.30
Mash—5 percent alfalfa	----------	.02
Mash—2.5 percent broccoli	----------	.02
Scratch corn	----------	.00
Fresh carrot root	[1] .14	[1] .13
Fresh carrot top	[1] .79	[1] .56
Frozen spinach	[1] .47	[1] .43

[1] Calculated on moisture-free basis.

LOSS OF CAROTENE IN STORED VEGETABLE LEAF MEALS

Since vegetable leaf meals will be stored for various periods of time and at various temperatures if they are used as feed supplements, it was considered advisable to determine the loss of carotene during storage. (See chap. 5 for data on carotene loss in extracts.) Figure 24 shows what carotene retention could be expected in certain leaf meals under various conditions of storage. All the meals were stored in closed containers, which were opened only at the time the sample was taken for analysis.

The carotene content of all the leaf meals studied decreased with time. In all cases there was a greater loss of carotene at 37° and 24° C. than at 5°. Blanching broccoli and lima bean leaves before drying did not change the rate at which the carotene was lost in storage at 24°. The rate of loss of carotene did not depend on the original con-

tent of the meal. Carrot top meal, which had 330 μg per gram, lost more carotene at 5° and 24° than lima bean and broccoli leaf meals, which had carotene contents of 100 and 750 μg per gram, respectively.

The three leaf meals that showed the greatest carotene retention—beet, rhubarb, and spinach— were the ones that contain the greatest percentages of oxalic acid (table 24). Mattill (*22*) reports that this

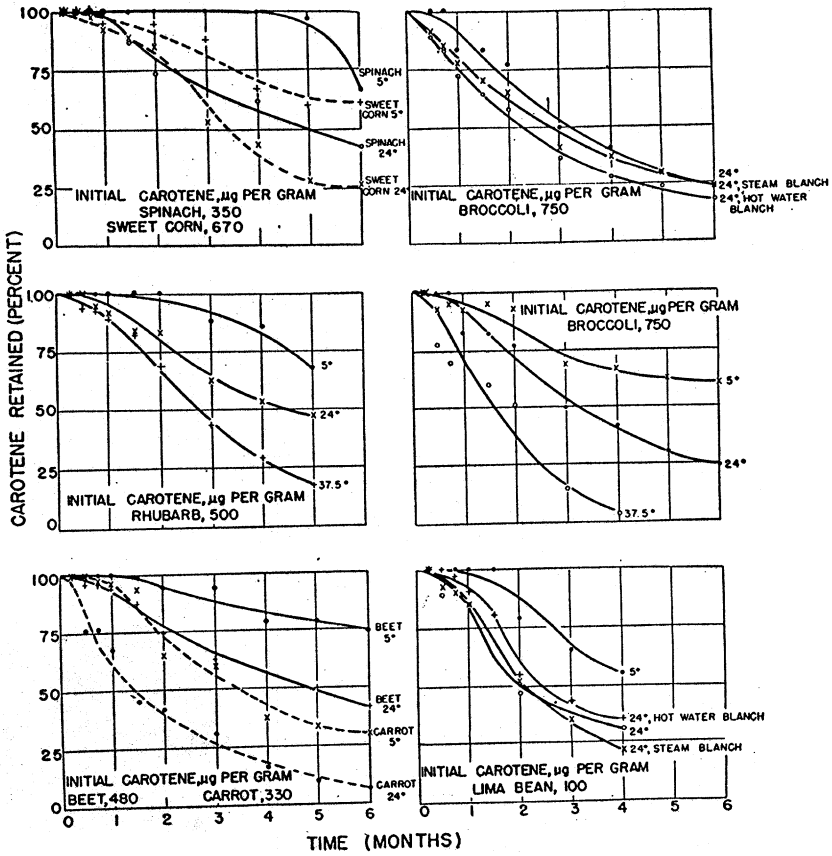


FIGURE 24.—Retention of carotene in stored vegetable leaf meals.

acid can act as an antioxidant to carotene. It may act in this manner in the beet, rhubarb, and spinach meals. One of the leaf meals that showed good carotene retention—rhubarb—has a high content of both tocopherol and oxalic acid. The other meal with a high tocopherol content—lima bean vine meal—has a low oxalic acid content and poor carotene retention. A great deal more work must be done on the relation of oxalic acid and tocopherol to loss of carotene before the role of such substances will be clearly understood.

CHAPTER 3

PREPARATION OF VEGETABLE LEAF MEALS

By D. A. Colker, *chemical engineer*, Roderick K. Eskew, *head, Chemical Engineering and Development Division*, and N. C. Aceto, *chemical engineer*

This chapter discusses the engineering factors involved in drying vegetable wastes on a large scale and describes a proposed commercial technique for producing high-quality leaf meal. The required factory equipment is specified. Other methods of processing are briefly discussed.

Typical yields and analyses of the leaf meals are given, and the processing costs are estimated. The data were obtained in pilot-plant operations in which thousands of pounds of raw material were processed.

The Process

The method developed at this Laboratory for drying leafy vegetable wastes is based on the principle of "fractional" drying. By subjecting the fresh material to a high-velocity stream of air at high temperature, the valuable tender leaf portions are quickly dried and embrittled, while the more resistant stem portions remain wet and tough. The embrittled leaves are readily separated from the moist stems by simple mechanical methods. Figure 25 shows typical sepa-

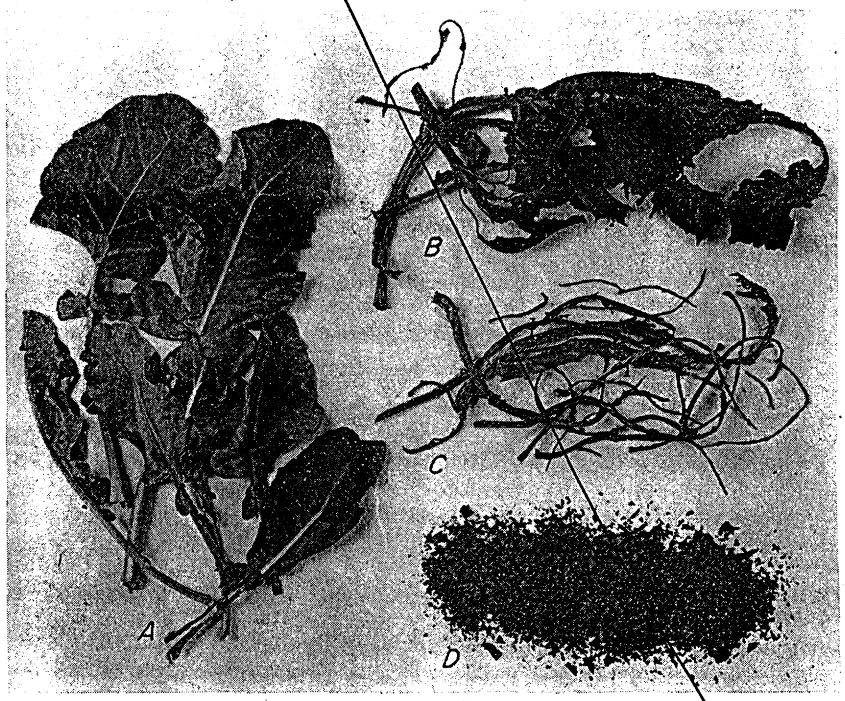


Figure 25.—Broccoli: *A*, fresh leaves and petioles; *B*, flash-dried unseparated material; *C*, stem and petiole fraction; *D*, leaf fraction.

rated fractions of a vegetable waste. This process not only separates the more valuable portions of the waste from the less valuable part but has the additional advantage of requiring less heat for evaporation. It has been satisfactory for all the wastes studied except pea vines, for which some modification is required.

It is possible to dry the moist stem residue separately for the production of a lower grade product. After the leaf portion has been separated, the stem part can be dried much more readily if it is first chopped into small pieces or crushed. The ultimate result is two products, one of high nutrient value, the other of low value. They could be marketed separately or mixed in any proportions to yield products having a nutrient value between the two extremes.

Experimental Studies

In processing each type of vegetable waste, the following factors were considered: (1) Yield of product, (2) composition of product (mainly protein, crude fiber, and carotene contents), (3) amount of water evaporated per unit weight of product, and (4) economics of the conditions and methods employed. Variables that affect one or more of these factors include: Condition of raw material, chopping before drying, pressing, and drying.

Condition of Raw Material

The physical condition of the raw material as received at the drier is important. Field wilting, for example, has a deleterious effect on the carotene content of green plant tissues. Serious bruising before field wilting accelerates this action. In the study of viner wastes from peas and lima beans, the leaf meals obtained by fractional drying and separating were considerably lower in carotene content than were the fresh, hand-separated leaves. Loss of carotene was slight in bruised lima bean leaves just leaving the viner, whereas bruised leaves analyzed several hours later showed a substantial reduction in carotene. Since the pilot-plant preparation of leaf meals included an unavoidable delay of several hours between "vining" and drying, one may assume that if the viner waste were introduced directly into a drier, the carotene values of the leaf meals would be higher than those obtained in this work.

Chopping Before Drying

The effect of chopping before drying has been studied with two types of vegetable wastes—carrot tops and broccoli leaves. The carrot tops consisted of numerous small leaves and thin stems, whereas the broccoli waste consisted of large, broad, succulent leaves and heavy stems. In each case, the fresh material was chopped in a standard radial-blade forage cutter. No significant difference was observed between carrot tops chopped to 1½-inch lengths and those that were not chopped. When they were dried and separated under the same conditions, they were practically the same in composition, yield, and amount of water evaporated per pound of product obtained. Chopping fresh carrot tops just before drying is recommended, however,

since chopped material is easier to feed to the drier uniformly and it makes possible somewhat heavier loads.

The results of chopping broccoli were quite different. Three sizes of cut were studied, averaging 2½, 1½, and ½ inches in length. The finer the chopping, the more the dried product lost its original bright-green color. It also appeared, though not conclusively, that the finer chopping resulted in evaporation of more water per pound of product obtained, probably because of the increased exposure of the interior surfaces of the large stems. Finally, the loss in carotene became greater as the chopping became finer, amounting to more than 35 percent for the finest cut. For these reasons, chopping broccoli waste before drying is undesirable.

Because of the entangled condition of pea vine waste, chopping is required to permit mechanical loading and handling in the drier. Although no tests were run to determine the effect of chopping on pea vine waste, it would probably have little effect on the ultimate composition if done immediately before drying, especially since fine chopping would not be required. Moreover, the yield and the separation after drying would not be affected, since pea vines are dried to completion and screen-separated rather than fractionally dried.

The large and succulent leaves of rhubarb become matted in the drier, slowing down the drying rate considerably. Therefore, chopping rhubarb before drying is essential in order to obtain a load that is economically feasible.

PRESSING

A few tests on a hydraulic dewatering press to investigate the possibility of reducing the initial moisture in some of the vegetable wastes before drying indicated that this procedure is actually harmful. Because the stem is generally bulkier than the leaf, dewatering takes place mainly in the stem. Pressing also breaks open the stems, causing them to dry more rapidly and making them unsuitable for fractional drying. This, together with the fact that the leaf becomes embedded in the stem as a result of pressing, prevents the subsequent separation of leaf from stem. Moreover, a valuable constituent might be lost in the expressed juices. On the basis of these results, dewatering field and packing house wastes before drying is not recommended.

DRYING

In the pilot-plant studies, a continuous triple-belt drier was used that was designed for through-air circulation and equipped for control of wet- and dry-bulb temperature, air velocity, and recirculation of air. This drier is shown in figure 26. Figure 27 shows the flash-dried material leaving the drier.

The effect of drying temperature was studied on hand-stripped leaves, mainly beet and broccoli. Hand-stripped leaves were chosen to eliminate the effect of drying temperature on the efficiency of separation of stem from leaf. The temperature ranged from 125° to 300° F., and the leaves were dried to approximately 5 percent moisture. The dried product was analyzed, and the results were compared with the results of analysis of undried hand-stripped leaves.

No significant differences were noted. A scorched odor was detected in the product dried at 280° and above. Scorching reduces the value of the product for feed purposes.

An inlet dry-bulb temperature of approximately 240° F. was eventually decided upon as most satisfactory in the equipment. Lower temperatures resulted in drying rates too slow for economical

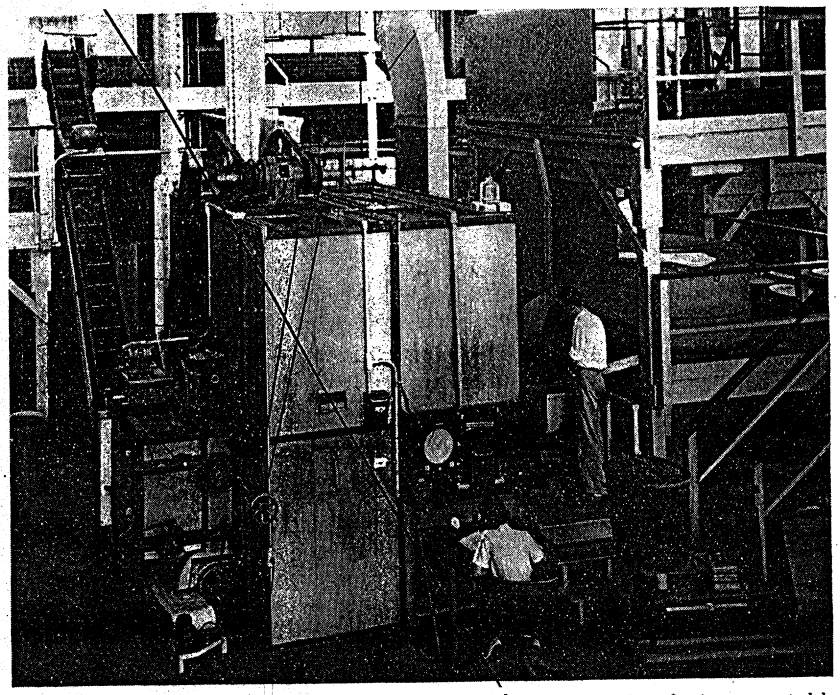


FIGURE 26.—Continuous triple-belt pilot-plant drier used for drying vegetable waste.

operation. Furthermore, slower drying caused more evaporation from the stem portions, resulting in greater fuel consumption and less efficient separation.

Temperatures between 240° F. and the scorching temperature might be employed with increased drying rates over that at 240°, and temperatures even above this scorching temperature might be used in the early stages of drying. However, certain difficulties are encountered when the drying rate is increased. For example, wastes of the broad-leaf type can be fractionally dried only if fresh areas are periodically exposed to the drying medium during the operation. This is accomplished by mechanically turning the material at the proper periods during the drying cycle. To avoid unnecessary drying of the stems and overdrying of the leaves, the material should be turned as soon as the leaves on the top layer become embrittled. This becomes increasingly difficult as the drying rate increases.

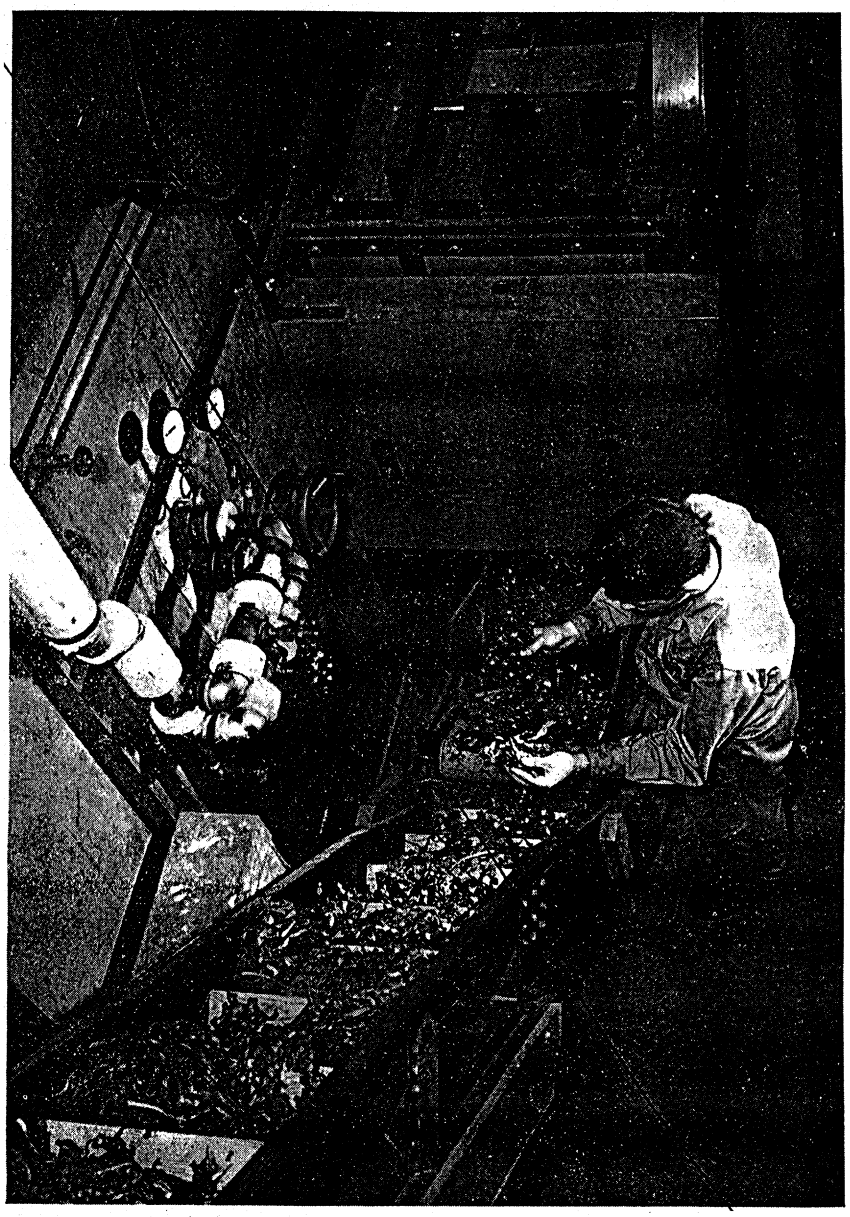


FIGURE 27.—Flash-dried vegetable waste leaving the pilot-plant drier and being elevated to the hammer mill.

The drier was operated at a dry-bulb temperature of 240° F., and the wet-bulb temperature was maintained at 140°–145° by continuously venting from the drier about 15 percent of the air.

Air flow in most of the experimental work was maintained at approximately 175 cubic feet of air per square foot of belt surface per minute. The air was directed down through the material, since this is typical of rapid, through-circulation, conveyor-type driers. The velocity through the material was actually much higher than this figure, since the free area through the material is considerably less than the area of the belt. A few tests with volumes of 100 cubic feet per square foot per minute showed considerable decrease of drying rate, together with the attendant disadvantages for fractional drying. At the higher velocity, loss of static pressure through the bed ranged from 0.3 to 0.6 inch of water, which is well within the limits of commercial practice. The depth of bed corresponding to this drop in pressure naturally varies with the stage of drying and the material being dried.

To simplify the operation of a commercial drier, studies were undertaken to arrive at a standard drying schedule for all the wastes, the only variation being that required in the rate of feed of fresh material (initial load per square foot) to adjust for the differences in initial moisture content and the physical nature of the material. The recommended initial load for each waste and the drying schedule are given under "Operating Procedure," page 62.

Equipment

A suggested assembly of the equipment is shown in the flow diagram in figure 28. The plant described would have an hourly production rate of 300 to 1,200 pounds of leaf meal, the actual quantity depending on the waste being processed.

Cutting

As mentioned previously, chopping is required for processing pea vines and rhubarb, and it is desirable for carrot tops. A cutting machine is also required if the wet stem residue from the drier is reprocessed after the leaf has been separated. A rotary forage cutter with readily removable screen and adjustable length of cut is the best type for these purposes. A screen having holes approximately 2 inches in diameter should be provided. It would be removed from the cutter when the fresh vegetable waste is chopped but would be installed when the residue is chopped for redrying. The cutter should be designed to produce a clean cut with a minimum of bruising when used without the screen. A machine having an hourly capacity of 3 to 4 tons of fresh waste would require a 7.5-horsepower motor and would cost approximately $725, including the cost of the motor.

Drying

Tests showed that a multiple-belt conveyor drier would be best adapted for maintaining a temperature of 230° to 250° F. for the air supplied to each belt, a volume of approximately 175 cubic feet of air per square foot per minute, and a periodic turning or rearrangement of the material. This drier has the advantage of being continuous

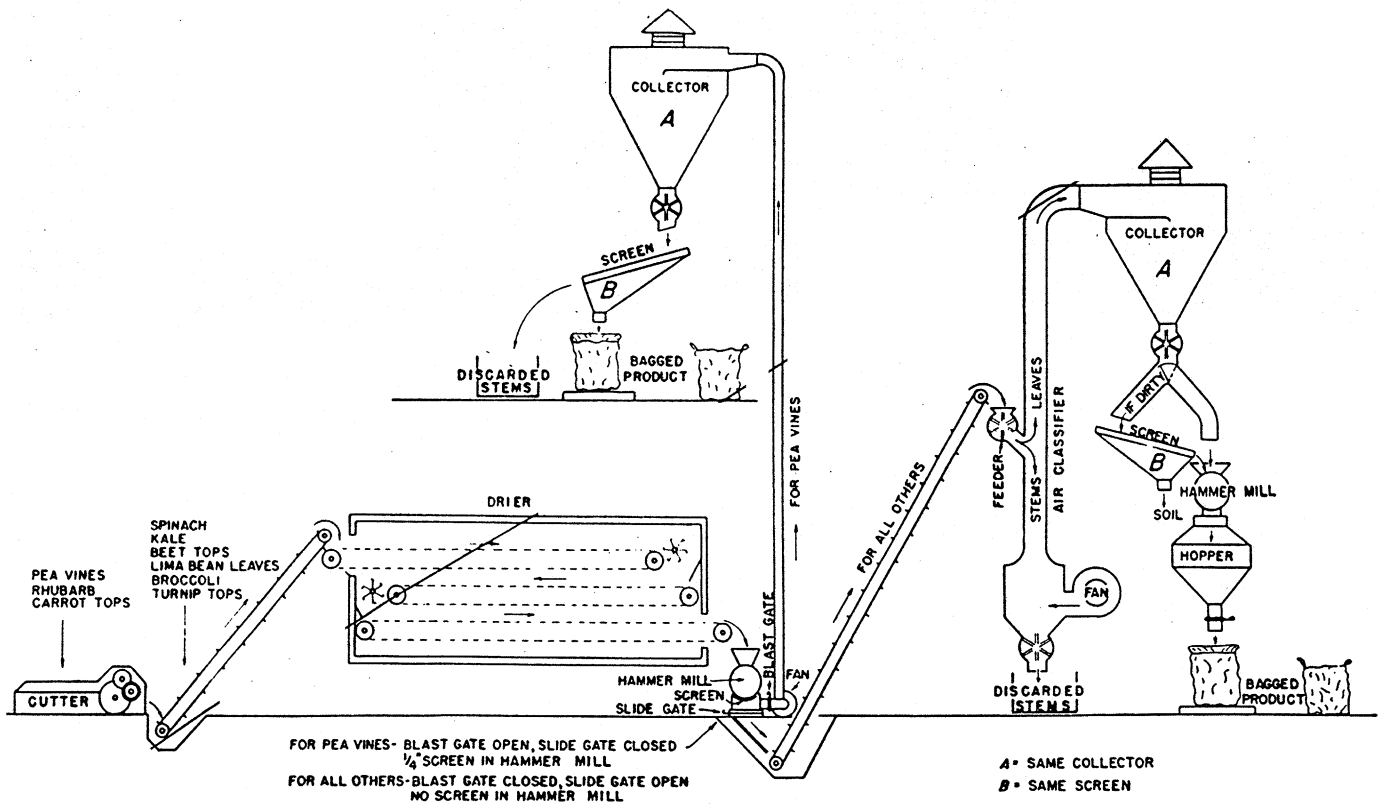


FIGURE 28.—Flow diagram for preparation of leaf meals from vegetable wastes.

as well as of allowing the turning action to take place within the heated zone. Furthermore, in a drier of this type the temperature of the air throughout the cycle can be controlled, and the air uniformly distributed with comparative ease.

The leafy structure of the vegetable waste becomes limp as soon as it is heated, sealing off the air passages and reducing circulation of air through the material. Thus, the maximum fresh load permissible per square foot of belt area is relatively light. Should this light load be maintained throughout, the drier would have to be abnormally long for a given capacity. As drying progresses, however, the plant shrinks and stiffens, permitting a heavier load while still maintaining sufficient porosity for circulation of air. This fact can be utilized to advantage by operating each succeeding belt at a lower speed. In this way, the quantity of material per square foot of belt area is progressively increased, thereby increasing the over-all capacity of the drier. The transfer from one belt to the next also achieves the required turning action. This procedure has the further advantage of balancing the evaporation load for each belt, since the drying rate is greatest in the early stages of drying and decreases as drying progresses. Therefore, in the later stages of drying, more material should be handled per square foot to make evaporation equivalent to that in the early stages. Finally, the successive increases in the belt load also equalize the loss of static pressure in the air passing through the belt during drying.

The greater the number of belts, the greater is the number of turnings, and theoretically, the greater is the over-all rate of drying. Practical considerations, however, limit the number of belts used in standard driers. In the pilot-plant drying work, it was found that a three-belt drier (two turnings), with successive doublings in the load, was adequate for successful results. Two arrangements are possible for a multiple-belt drier, the multiple-deck type and the extended type. Each has advantages and disadvantages, depending not only on the particular features of the drier but also on local conditions.

In general, the drier should consist essentially of conveyor belts constructed of sturdy, flexible, wire mesh ($\frac{3}{16}$-inch maximum holes), preferably galvanized, with a retaining apron at least 8 inches high on each side of the last belt. The speed of the belts should preferably be capable of variation. This will greatly increase the utility of the drier at only a slight increase in cost. A feeding unit of variable speed, with a loading hopper, should also be provided. Suitable kicking devices synchronized with the movement of the belt should be included at the discharge end of each belt to open the mat of material as it falls from one belt to the next.

Sufficient fan capacity and duct work should be provided to maintain the required air flow, to distribute the air uniformly over the conveyor area, and to exhaust an adequate amount of waste air at suitable locations.

The drier can be heated most economically by a mixture of air and flue gases. The furnace should be designed to operate at temperatures adequate to give clean flue gases. Suitable automatic controls for maintaining the required temperature in the drier should be furnished, and in addition, a safety device should be provided to vent the flue

gases from the burners in the event of an emergency causing overheating in the drier.

The entire drier should be adequately supported, and it should be enclosed with materials having good insulating value. By using the information given here, the detailed design of the drier can be worked out with any reputable manufacturer of drying machinery.

The actual size of the drier required would naturally depend on the quantities of waste available and hourly capacities desired, but for the purpose of general discussion and comparison of capacities for different wastes, a drier having a total drying area of 930 square feet has been selected. With a belt 8½ feet wide, a three-belt multiple-deck drier having this drying area would be approximately 40 feet long and would require a total of approximately 65 horsepower for fans and conveyors. A unit of this size having the general characteristics outlined above would cost about $40,000, including the cost of installation.

MECHANICAL SEPARATION

In AIC–76 [8] "Processing Vegetable Wastes for High-Protein-High-Vitamin Leaf Meals," a continuous trommel was recommended for separating the leaf blade fraction from the stems. This was based upon successful pilot-plant operation with a batch trommel. However, it was found to be impracticable to construct a continuous trommel that would serve satisfactorily for vegetable wastes having widely different physical characteristics.

A simple practical procedure has now been devised for accomplishing this separation. It consists in using a hammer mill, run at relatively low speed and having no screen, to strip the crisp leaves from the limp stems. Actual separation of the two fractions is then done by air classification. By varying the hammer mill tip speed from 3,600 to 5,500 feet per minute and the air velocity in the classifier from approximately 500 to 600 feet per minute, effective separations were obtained on all vegetable wastes tested.

A hammer mill tip speed of about 3,600 feet per minute is recommended for all wastes except rhubarb and beet tops, for which 5,500 and 4,700 feet per minute, respectively, are recommended. These tip speeds were used in the pilot-plant experiments, where the diameter of the hammer mill rotor was 10 inches. In order to take care of the output of the drier just described, a hammer mill having a capacity of 1 ton per hour of drier discharge would be required. This would be larger than the pilot-plant unit and hence would have to be operated at fewer revolutions per minute to obtain the tip speeds recommended here. Deviations of plus or minus 10 percent from the recommended tip speeds should be permissible.

The hammer mill should have three rows of hammers, each row consisting of one-sixteenth inch thick, single-end, square-edge hammers. It should also be equipped with a magnetic separator on the feed end, a screen having ¼-inch openings for use in processing pea vines, a discharge fan, and duct work. This unit would require 12

[8] COLKER, DAVID A., and ESKEW, RODERICK K. PROCESSING VEGETABLE WASTES FOR HIGH-PROTEIN, HIGH-VITAMIN LEAF MEALS. Bureau of Agricultural and Industrial Chemistry AIC–76. 17 pp., illus. 1945. [Mimeographed.]

horsepower for operation. The total cost would be approximately $1,700, including the cost of the motors and wiring.

An air classifier equipped with a blower, cyclone separator, and star feeders on the feed and discharge ends would cost approximately $650, including the cost of a 2-horsepower motor with a variable speed regulator to drive the blower and three ¼-horsepower motors to drive the star feeders, as well as the cost of piping and wiring.

In addition, an inclined cleated-belt conveyor would be required to carry the material from the hammer mill to the air classifier. Since the material is bulky, this conveyor should have fairly large volumetric capacity. Such a unit would require a 2-horsepower motor, and installed and ready to run, would cost approximately $400.

SCREENING

A single-stage vibrating screen of a conventional type is used. Two readily interchangeable sieves of the self-cleaning type, each having a screening area of at least 30 square feet, are required. One is used to remove the soil from the leaf fraction before grinding. This should be 60 mesh (0.009-inch opening). The other, used in processing pea vines, should be 20 mesh (0.03-inch opening). Such a screen requires a 2-horsepower motor for operation. It costs about $1,325, including the cost of the motor and wiring.

GRINDING

A hammer mill of the type generally used in producing poultry feed meals is required for grinding the dried leaf fraction. In addition to the standard screen for producing 1/20-inch meal, it should be provided with a hopper having a two-way sacker. This unit requires a 5-horsepower motor. The cost of the unit is approximately $700, including the cost of the motor, wiring, and foundations.

Operating Procedure

On the basis of the pilot-plant work, the following operating procedure is recommended for commercial use.

The fresh vegetable waste is put into a hopper at ground level, from which a mechanical feeding device loads the drier belt uniformly at a predetermined rate. In drying pea vines, carrot tops, and rhubarb, the waste is cut in a forage cutter set for coarse chopping before it is put into the feed hopper of the drier. Pea vines are cut into 3- to 6-inch pieces, and carrot tops and rhubarb into 1½- to 3-inch pieces.

The drier is operated according to the following drying schedule. This schedule may be subjected to some slight modification when used on a commercial scale, since the procedure recommended is based on tests in a pilot-plant unit. On the whole, however, the results should be readily reproducible commercially, since conditions maintained in the experimental drier can be duplicated in a large conveyor-type drier.

Table 26 shows the load per square foot of belt area, together with the average moisture contents of the various wastes. These moisture

contents were encountered in pilot-plant operations in 1946. They are somewhat above the averages found in other years. Hence heavier loads than those shown will at times be possible.

TABLE 26.—*Drier belt loads for various vegetable wastes*

Vegetable waste	Average initial moisture	Fresh weight per square foot of first belt	Dry weight per square foot of—			Average dry weight per square foot of drying surface
			First belt	Second belt	Third belt	
	Percent	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Broccoli [1]	88. 5	1. 13	0. 13	0. 26	0. 52	0. 30
Beet tops [2]	92. 0	. 86	. 07	. 14	. 28	. 16
Carrot tops	80. 7	1. 38	. 27	. 54	1. 08	. 63
Lima bean leaves [3]	73. 8	1. 15	. 30	. 60	1. 20	. 70
Pea vines	81. 5	1. 03	. 19	. 38	. 76	. 44
Rhubarb	88. 6	. 72	. 08	. 16	. 32	. 19

[1] Waste from the sorting belt in preparing heads for market or freezing.
[2] Surplus of material grown for canning.
[3] The apron fraction, which is the side fraction from the viner and consists mainly of broken leaves. It was caught before it could mix with the end fraction, which is mainly stems.

The importance of the moisture content of the waste is obvious. In drying beet tops with a moisture content of 92 percent, the drier produced only 265 pounds of leaf meal per hour at a cost of nearly $92 per ton, whereas the same drier operating on beet tops having 88 percent moisture would produce approximately 415 pounds of leaf meal per hour at about $59 per ton. Similar relationships apply on all wastes.

The method of operating the drier consists simply in running the first belt at such a speed that the vegetable material is carried for a period of 3.5 minutes, and then loading the belt according to the waste being processed, as shown in table 26. Where the moisture content differs from those shown, adjustments in the load must be made. The second belt is operated at half the speed of the first; thus the material remains on the second belt for 7 minutes at double the original load. The third belt is operated at half the speed of the second; thus the material remains on the third belt for 14 minutes at four times the original load. On this basis, with a total drying time of about 24 minutes, the average dry weight load per square foot for the entire drier is one-third the sum of the individual loads on each belt. To operate on this schedule, the temperature of the air entering to each belt should be maintained at approximately 240° F., and the volume of air should be approximately 175 cubic feet per minute for each square foot of belt area.

From the drier, the product is discharged directly into the hammer mill, which is operated at 3,600 to 5,500 feet per minute, depending on the waste being processed. After passing through the hammer mill, the material is discharged on to the cleated-belt conveyor, which carries it to the air classifier. The wet residue drops through the classifier and is continuously released through a star feeder and carried away for subsequent chopping and redrying or for disposal.

TABLE 27.—*Average yield and composition of leaf meals from various vegetable wastes* [1]

Vegetable waste	Moisture	Leaf meal								Wet residue		
		Yield [2]	Moisture	Yield [3]	Composition (bone-dry basis)					Yield [2]	Moisture	Yield [3]
					Protein	Crude fiber	Ether extract	Carotene	Riboflavin			
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Micrograms per gram* [4]	*Micrograms per gram*	*Percent*	*Percent*	*Percent*
Broccoli	88. 5	6. 6	5. 2	54. 0	35. 7	6. 1	9. 5	460	24. 7	[5] 19. 4	72. 7	46. 0
Beet tops	92. 0	5. 6	4. 4	67. 5	29. 6	6. 2	7. 6	460	18. 4	5. 5	52. 8	32. 5
Carrot tops	80. 7	9. 6	7. 0	46. 0	18. 0	8. 5	5. 1	158	10. 1	32. 0	67. 5	54. 0
Lima bean leaves [6]	73. 8	17. 8	3. 2	65. 0	21. 2	6. 9	6. 0	297	14. 0	8. 1	3. 9	30. 0
Pea vines	81. 5	9. 7	6. 8	49. 0	14. 6	18. 8	4. 1	85	16. 8	[7] 10. 7	12. 3	[7] 51. 0
Rhubarb	88. 6	10. 7	5. 7	88. 2	27. 4	6. 8	------	285	7. 0	2. 4	44. 5	11. 8

[1] For raw material described in table 26.
[2] On basis of fresh material.
[3] On basis of bone-dry material.
[4] Micrograms per gram, or parts per million, of carotene x 754 = International Units per pound.
[5] A typical broccoli air-classifier residue when chopped and dried contained 21.3 percent protein, 16.9 percent crude fiber, 3.5 percent ether extract, 43 micrograms per gram of carotene, and 7.1 micrograms per gram of riboflavin.
[6] Soil screened from the dried leaf fraction amounted to 1.3 percent on the fresh basis and 5 percent on the basis of the bone-dry material.
[7] Dry residue. Pea vines are totally dried before separation.

At the same time, the leaf fraction is carried by the stream of air through the cyclone collector to any of the following operations, depending on the use intended:

Bagging. (When finely ground material is not required.)

Hammer milling, then baggging. (For use as poultry feed fortifiers.)

Screening (for removal of fine soil when the vegetable waste is dirty), followed by bagging or by hammer milling and then bagging.

In processing pea vines, the operations following drying are somewhat different. The dry product goes to a hammer mill operated at 7,100 feet per minute, from which it passes through a screen having ¼-inch openings. The hammer-milled product is carried through the cyclone collector and discharged on a vibrating screen with a 20-mesh sieve, which separates the residue from the leaf in about a 50–50 ratio. The leaf can be bagged directly from the screen. The residue is also dry at this point and can be bagged for use as chicken litter or for other purposes.

Yields and Analyses

As a result of numerous pilot-plant runs, the average yield of leaf meal from each of the vegetable wastes studied was determined. These data, given in table 27, indicate that the yield varies with the moisture content of the waste. Table 27 also gives the average composition of the leaf meals, as well as the yield of stem residue and its average moisture content.

Table 28 indicates the hourly performance of the drier for each of these vegetable wastes. Since the amount of evaporation is nearly constant, the weight of dry-product output is nearly proportional to the percentage of dry solids in the waste.

Table 28.—*Hourly performance of 3-belt drier with 930 square feet of drying area* [1]

Vegetable waste	Fresh material	Leaf meal (air-dry basis)	Wet residue	Water evaporated
	Pounds per hour	*Pounds per hour*	*Pounds per hour*	*Pounds per hour*
Broccoli	6, 140	405	1, 190	4, 545
Beet tops	4, 700	265	260	4, 175
Carrot tops	7, 700	735	2, 500	4, 465
Lima bean leaves	6, 300	[2] 1, 120	510	4, 590
Pea vines	5, 600	545	[3] 600	4, 455
Rhubarb	4, 100	430	95	[4] 3, 575

[1] For raw material described in table 26.
[2] 80 pounds of soil per hour was screened off from the dried leaf fraction.
[3] Dry residue. Pea vines are totally dried before separation.
[4] Drier load was limited because of matting.

Cost of Processing

Since the cost of the commercial processing of vegetable wastes will depend on many factors, which will be different in each plant, only a general estimate of the over-all cost can be made. The principal costs involved and a method of computing them are explained here, and on

the basis of stated assumptions the average cost of processing each waste is given. These figures include all costs except charges for raw material, haulage, storage of product, and rent.

OPERATING COSTS

Operating costs consist mainly of the costs of fuel, power, labor, supplies, maintenance, and clerical work. The type of fuel will depend on the design of the drier and the relative cost of the various fuels delivered to the plant. For purposes of computation, the use of fuel oil with a thermal value of 145,000 B. t. u. per gallon is assumed. Fuel consumption is based on a drier efficiency of 2,000 B. t. u. per pound of water evaporated. The labor for operating the drier and bagging the product should consist of one supervisor and three laborers for each 8-hour shift. Rates for labor and clerical work, and the costs of power, miscellaneous supplies, and maintenance are also assumed. Since the cost of bags for shipping the dried product is charged to the consumer, this cost is not included. The assumed costs are: Fuel, $0.04 per gallon; power, $0.025 per kilowatt-hour; skilled labor, $1.25 per man-hour; unskilled labor, $0.90 per man-hour; clerical, $0.75 per man-hour for 8 hours, or $0.25 per operating hour; maintenance and supplies, $0.40 per operating hour.

With these assumed costs, the operating cost per hour has been calculated for each waste studied. Table 29 shows these data. The yearly operating costs, however, will naturally depend on the proportions of the different wastes processed.

TABLE 29.—*Cost of processing various vegetable wastes* [1]

Vegetable waste	Operating cost per hour	Total cost per ton of product
Broccoli	$9. 01	[2] $61. 20
Broccoli	8. 98	[3] 12. 60
Beet tops	8. 80	91. 90
Carrot tops	9. 14	34. 10
Lima bean leaves	9. 03	22. 18
Pea vines	8. 96	45. 30
Rhubarb	8. 64	55. 90

[1] Raw material described in table 26.
[2] Leaf meal.
[3] Dried air-classifier residue.

FIXED COSTS

Fixed costs are based on the total investment, which is summarized below.

	Cost
Equipment:	
Cutter	$725
Drier	40, 000
Hammer mill	1, 700
Screen	1, 325
Air classifier	650

	Cost
Equipment—Continued	
Conveyor	$400
Hammer mill	700
Total	45,500
Building	7,000
Total investment	52,500

For estimating the yearly fixed costs, the following percentages are assumed:

	Percent of investment per year
Amortization	10
Interest	4.5
Insurance	1.5
Taxes	2
Total	18.0

For the purpose of calculating fixed costs on an hourly basis, a total of 2,800 operating hours per season is assumed. Obviously, the greater the number of hours, the lower will be the fixed costs per hour. Under certain conditions, for example, if a lull is expected in packing house operations, it might prove economical for the processor himself to grow some of the more nutritionally rich products just for drying. Experiments on growing closely planted broccoli for this purpose are discussed in chapter 2.

TOTAL COSTS

Table 29 shows the total cost per ton of leaf meal for each vegetable waste studied. The following calculation of the cost of processing broccoli waste for leaf meal is given as a sample calculation.

	Cost per operating hour
Operating costs:	
Fuel:	
$\frac{4{,}550 \text{ (lbs. water evap. per hr.)} \times 2{,}000 \text{ (B. t. u. per lb. water evap.)}}{145{,}000 \text{ (B. t. u. per gallon)}} \times \$0.04$	$2.51
Power (including power for screening and grinding):	
$\frac{86\tfrac{3}{4} \text{ (required horsepower)} \times 0.746 \text{ (kilowatt per horsepower)}}{0.85 \text{ (motor efficiency)}} \times \$0.025$	1.90
Labor:	
One supervisor at $1.25	
Three laborers at $0.90 each	
One clerk at $0.25 each	4.20
Maintenance and supplies	.40
Total	9.01
Fixed cost:	
$\frac{\$52{,}500 \text{ (total investment)}}{2{,}800 \text{ (operating hours)}} \times 0.18 \text{ (percent of investment per year)}$	3.38
Total	3.38
Grand total	12.39
Cost of processing broccoli waste	$12.39 per hour.
Cost of producing broccoli leaf meal $\left(\frac{\$12.39}{405}\right)$	$0.0306 per pound.
or ($0.0306 × 2,000)	$61.20 per ton.

In processing broccoli waste, the residue from the air classifier has considerable value (table 27). The wet residue can be redried in the same drier if it is chopped before drying. Table 28 shows that operating the drier for 1 hour produces 405 pounds of leaf meal and also 1,190 pounds of residue having 72.7 percent moisture. This residue, dried to 10 percent moisture, would yield 361 pounds of dried residue and would require the evaporation of 829 pounds of water. Since the drier has an average evaporating capacity of 4,500 pounds of water per hour, it should be capable of producing 1,960 pounds of dried residue per hour. This would dry in 1 hour the residue produced from operating the drier for about 5½ hours for production of leaf meal. The cost of drying the residue, calculated in the same manner as the cost of the meal, is $0.0063 per pound, or $12.60 per ton.

The cost of processing the entire broccoli waste may be calculated as follows:

Cost of preparing leaf meal (405 lbs. × $0.0306 per lb.)	$12.39
Cost of drying residue (361 lbs. × $0.0063 per lb.)	2.27
Total (766 lbs.)	14.66

Cost of processing entire waste $\left(\frac{\$14.66}{766} \times 2{,}000\right) = \$38.28$ per ton.

Other Methods of Processing

The major difference in other methods of processing is in the type of drying equipment employed. Although driers of other types were not used in these experiments, some generalizations can be made as to their possible utilization on the basis of the conditions required in the drier and the relative economy of the different types. Three general types of drying equipment will be discussed here—the tray-truck, the loft, and the rotary. Obviously, vacuum driers for this purpose would be out of the question.

The tray-truck drier is used either as a batch unit in a cabinet or a continuous unit in a tunnel. In either case, the truck is equipped with numerous trays, thus making possible a heavy load per cubic foot of drier. On the other hand, there are two distinct disadvantages in using this drying method for processing vegetable wastes. The first is that large quantities of bulky material are required to produce an appreciable quantity of product. Since loading trays is costly, tray drying may prove uneconomical. A second disadvantage is that in fractional drying of many materials, a periodic turning over or redistribution of the bed is necessary. This is practically impossible in a tray drier. The only alternative to this turning process is to use extremely light loads per tray, but this would nullify the advantage mentioned. Thus, tray-truck drying is not economically feasible for processing vegetable wastes.

The loft or kiln drier ordinarily consists of a perforated metal or slotted wooden floor erected over a direct source of heat. In the majority of these installations, the draft is maintained through natural convection. Although the large holding capacity permits a low-cost loading operation, such a unit is unsuited for the rapid rate required in fractional drying. The drying rate is low, mainly because of limited air velocity. Furthermore, if some fractional drying were effected,

the fragile dried portion would be seriously rehydrated during unloading, and part of it would be lost through the loft floor. Thus it would appear that fractional drying would not be practicable in a loft drier. When the entire waste material is to be dried, however, this type of drier might be used.

There are many variations of the rotary drier. In the type used for most forage drying, hot air dries the finely chopped material and conveys it through the drier in a short time. The capital cost of such a drier is generally less per unit of evaporative capacity than the cost of the type recommended in this bulletin.

It can be seen at once that the possibilities of using this type of rotary drier differ for different wastes. For such materials as chopped pea vines, chopped carrot tops, and possibly lima bean vines, it might prove satisfactory. Since the entire product would be dried, the subsequent separation would be taken care of much in the same manner as that described for pea vines ("Operating procedure," page 65). With the exception of chopped pea vines, the products obtained by this method of drying and separating would probably not be so pure as those obtained by fractional drying and separating.

Considerably more difficulty would be encountered in using this type of drier for the more succulent, broad-leaf wastes, such as broccoli, beet, kale, and spinach. Fine chopping, which is a necessary preliminary in the use of the air-conveying type of rotary drier, causes considerable juicing and pulping, resulting in difficulty in feeding the drier. Furthermore, as shown under "Experimental studies," page 55, chopping broccoli waste results in a product having a lower carotene value. This can be expected to prove true for other materials of the same type. Thus, although some kinds of rotary driers might be used for certain wastes, in general the high-temperature, air-conveying driers are not recommended for processing broad-leaf wastes.

CHAPTER 4

USE OF VEGETABLE LEAF MEALS IN POULTRY FEEDS

By A. E. Tomhave, *poultry and animal husbandman,* and Edmund Hoffmann, *assistant animal husbandman, Delaware Agricultural Experiment Station;* and Edward G. Kelley, *chemist,* and Monroe E. Wall, *chemist, Eastern Regional Research Laboratory*

The suitability of leaf meals made from vegetable wastes as components of poultry feeds was tested in a series of six runs with growing mashes and in one run each with laying and breeding mashes.

Run 1.—Preliminary Investigation on the Use of Vegetable Leaf Meals in Broiler Rations

In October 1943, a preliminary investigation was undertaken which was designed largely to discover whether vegetable leaf meals had any harmful effects when fed to poultry and to determine whether the vitamin contents of the meals were readily utilized. Only a general description of the investigation is given here. A detailed report of these tests has been published by the Delaware Agricultural Experiment Station (*41*).

PROCEDURE

Fourteen hundred New Hampshire chicks hatched on October 26, 1943, were used. They were divided into 7 groups of 200 chicks each, and each group was housed in a 12- by 12-foot colony house provided with a 6- by 6-foot sun porch, to which the chicks had access at all times. Coal stoves were used for heating. The management as well as the equipment of the colony houses was as nearly identical as possible. The experimental diets and water were offered ad libitum, and feed consumption was recorded weekly. The birds were group-weighed weekly except at 8 and 14 weeks of age, when individual weights were taken and the birds were scored for feathering and pigmentation.

Table 30 shows the formula for the basal diet. Table 31 gives the analyses of the experimental diets.

TABLE 30.—*Formula for basal diet in run 1*

Ingredients	Percent	Ingredients	Percent
Ground yellow corn	30	Steamed bone meal	1
Ground oats	15	Oystershell flour	1.5
Wheat bran	10	Salt mix [2]	.5
Cracked wheat	10	D-activated animal sterol [3]	.05
Soybean oil meal	20		
Meat scrap [1]	5	Total	93.05

[1] 50 percent protein.
[2] A mixture of 100 pounds of salt and 2 pounds of anhydrous manganous sulfate.
[3] Contained 2,000 I. U. of vitamin D per gram.

RESULTS

MORTALITY

Table 31 shows that all the leaf meals used may be fed to broilers at a level as high as 8 percent of the total feed intake with no harmful effects. There were no significant differences in mortality between the groups fed the various vegetable leaf meals and the group fed alfalfa meal. The control group, fed a diet containing no alfalfa or leaf meal supplement, had about six times the mortality of the other groups.

GROWTH

At the end of 14 weeks, the broccoli and carrot leaf meals had produced heavier birds than had the alfalfa meal, and lima bean vine and turnip leaf meals had produced birds as heavy as the ones fed alfalfa meal. Broilers fed pea vine meal lagged approximately one-half pound per bird behind the group fed alfalfa meal. As shown in table 31, the carotene content of the pea vine meal used in this experiment was lower than that of the other meals, which probably accounted for the poor growth obtained with this diet.

The poor growth of the chicks in this experiment—only about 80 percent of normal—was due to the poor quality of the soybean oil meal

TABLE 31.—*Analyses of diets in run 1 and results of feeding tests at end of 14 weeks*

Pen No.	Diet	Analyses of diet				Palatability index [1] of diet	Mortality of birds	Average weight of birds	Average feed consumed per bird	Feed consumed per pound of gain in weight of birds	Pigmentation index [2] of birds
		Protein	Crude fiber	Riboflavin	Carotene as vitamin A						
		Percent	*Percent*	*Micrograms per pound*	*International Units per pound*		*Percent*	*Pounds*	*Pounds*	*Pounds*	
1	Basal +8 percent alfalfa meal	20. 8	6. 5	1, 410	4, 500	--------	11	2. 55	11. 78	4. 6	48
2	Basal+8 percent pea vine meal	20. 0	5. 0	1, 568	2, 200	62	15	2. 10	10. 71	5. 1	48
3	Basal+8 percent lima bean vine meal	19. 8	4. 4	1, 290	9, 000	78	7	2. 51	11. 76	4. 6	59
4	Basal+8 percent turnip leaf meal	20. 4	4. 5	1, 558	21, 000	87	11	2. 59	11. 46	4. 4	66
5	Basal+8 percent broccoli leaf meal	21. 6	4. 3	1, 976	26, 400	96	9	2. 73	11. 31	4. 3	95
6	Basal+8 percent carrot leaf meal	19. 4	5. 2	1, 430	5, 900	93	6	2. 65	11. 87	4. 5	53
7	Control [3]	20. 2	3. 8	1, 290	[4] 1. 100	--------	60	1. 94	9. 11	4. 7	6

[1] An index of 100 would mean that broilers given their choice would eat that diet to the complete exclusion of a diet supplemented with alfalfa meal.

[2] An index of 100 would mean that every bird in the group had scored perfect in pigmentation.

[3] The control diet was the same as the basal diet except that it contained 35 percent ground yellow corn and 22 percent soybean oil meal instead of 30 and 20 percent, respectively.

[4] Calculated; none found by analysis.

available at the time the diets were mixed. This was confirmed in a separate experiment, in which the meal was compared with one of good quality that became available during the run.

FEED EFFICIENCY

Broilers fed broccoli and turnip leaf meals used their feed a little more efficiently than those fed alfalfa meal; the birds fed lima bean vine and carrot leaf meals used approximately the same amount of feed per pound of gain as those fed alfalfa meal. The pea vine meal was definitely less efficient than the others.

PIGMENTATION

The degree of pigmentation induced by a diet is important because poultrymen and poultry buyers alike use it as an index of a bird's health and finish. In order to evaluate the degree of pigmentation of the broilers fed the various diets, the birds were scored for shank color at 8 weeks of age. Possible scores ran from 1, a deep orange yellow, to 4, which was definitely whitish. Afterwards the scores were changed to index numbers to throw the differences into sharper contrast.

Table 31 shows that the broccoli-fed birds had almost perfect pigmentation, only a few birds scoring as low as 2. The group fed turnip tops was almost as good, even though the recorded data place them about 30 percent below the broccoli-fed group. A large number of birds in this group had a degree of pigmentation between 1 and 2 but were put in the 2 group because it did not seem advisable to introduce a new value in the scoring system. Careful observation of the birds in their houses suggested that a score midway between the score of the group fed broccoli leaf meal and that of the group fed lima bean vine meal, which was third best, would be a more accurate evaluation of the shank color of the group fed the turnip leaf meal.

PALATABILITY

The average feed consumption per bird was remarkably uniform (table 31), indicating that all diets were equally palatable. When given their choice of the seven diets, no difference in the amount of feed consumed was noted. When the leaf meals only were fed in separate hoppers and the birds were given their choice of the vegetable leaf meals or alfalfa meal, they showed a strong preference for the vegetable leaf meals, as indicated by the palatability index in table 31.

Run 2.—Broccoli Leaf Meal and Carotene Extracted From it as Vitamin A Supplements in Broiler Rations

In March 1944, an experiment was started to study the value of broccoli leaf meal and a carotene extract made from the meal as vitamin A supplements in broiler rations and to compare the carotene with fish liver oil as sources of this vitamin. The broccoli leaf meal was similar to that used in run 1.

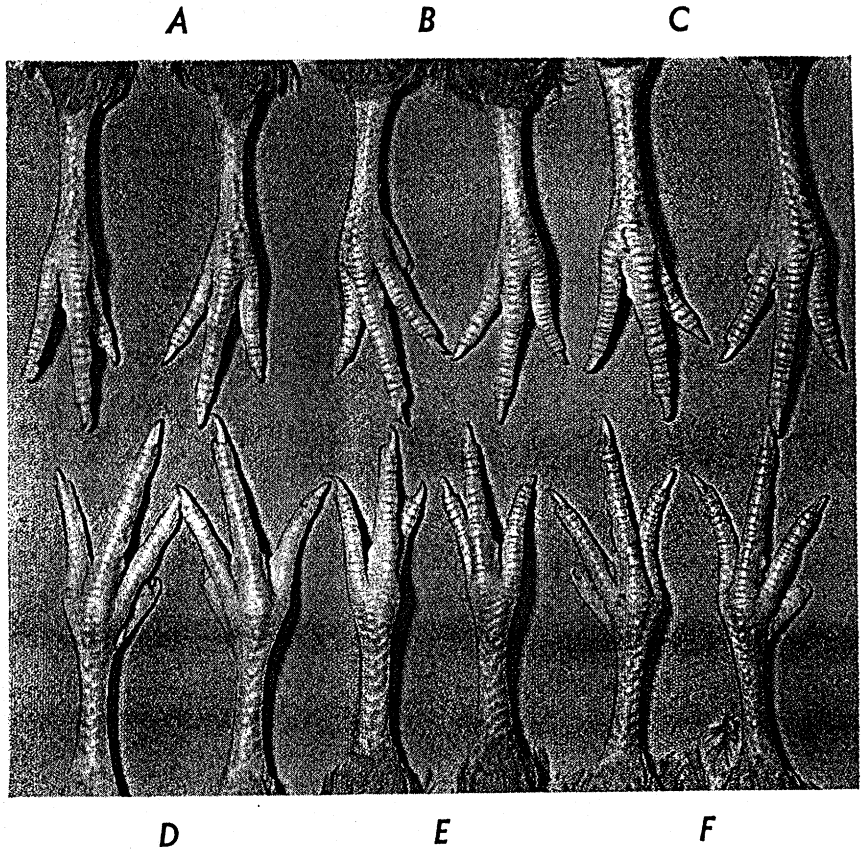


PLATE 1

Pigmentation of shanks of chickens fed diets containing 6 percent alfalfa meal (*A*), and 1½ percent (*B*), 3 percent (*C*), 6 percent (*D*), 10 percent (*E*), and 30 percent (*F*) of broccoli leaf meal.

PROCEDURE

Forty 1-day-old, New Hampshire, male chicks, divided into two groups of 20 birds each and confined to batteries, were fed each diet. Table 32 shows the formula for the basal diet, and table 33 shows the various supplements added and the vitamin A value of each diet. Individual weights were taken at 6 and at 8½ weeks, and shank pigmentation was graded at 8½ weeks by the procedure used in run 1.

TABLE 32.—*Formula for basal diet in run 2.*

Ingredients	Percent	Ingredients	Percent
Ground yellow corn	14	Meat scrap	5
Ground oats	15	Oystershell flour	1.5
Wheat bran	15	Salt mix [1]	.5
Cracked wheat	23	D-activated animal sterol [2]	.05
Soybean oil meal	20		
Dried milk	2	Total	97.05

[1] A mixture of 100 pounds of salt and 2 pounds of anhydrous manganous sulfate.
[2] Contained 2,000 I. U. of vitamin D per gram.

TABLE 33.—*Results of feeding tests in run 2 at end of 6 and 8½ weeks*

Pen No.	Diet	Vitamin A content	Average weight of birds at—		Pigmentation index of birds
			6 weeks	8½ weeks	
		International Units per pound	*Pounds*	*Pounds*	
1	Basal	[1] 477	1.14	1.77	24
2	Basal + 3 percent broccoli leaf meal	9,837	1.30	2.36	94
3	Basal + 3 percent extracted broccoli leaf meal	477	1.19	1.96	43
4	Same as for pen 3 + high level of carotene concentrate	9,837	1.33	2.28	59
5	Same as for pen 3 + commercial crystalline carotene	9,837	1.33	2.32	59
6	Same as for pen 3 + low level of carotene concentrate	1,837	1.34	2.20	61
7	Basal + distiller's solubles + carotene concentrate	9,837	1.36	2.35	41
8	Same as for pen 3 + high level of vitamin A from fish liver oil	[2] 9,837	1.37	2.31	64
9	Same as for pen 3 + low level of vitamin A from fish liver oil	[2] 1,837	1.32	2.20	66

[1] Calculated; none found by analysis.
[2] Calculated from the vitamin A content of fish liver oil.

RESULTS

Table 33 shows the average weights of the birds at 6 and at 8½ weeks and the pigmentation index at 8½ weeks.

Broccoli carotene appeared to be satisfactory as a source of vitamin A. At the high vitamin level, growth was as good on the 3 percent broccoli leaf meal (pen 2) and on the carotene concentrate (pen 4)

as it was on the fish liver oil (pen 8). Crystalline carotene (pen 5) was also satisfactory at this vitamin level. The factor determining growth in this experiment was vitamin A rather than any other factor contributed by the broccoli leaf meal, since good growth was also obtained with the carotene concentrate when distiller's solubles (pen 7) was substituted for the extracted broccoli leaf meal (pen 4). At the lower vitamin A level, the growth rate was slower than at the higher level, but was the same with the carotene (pen 6) as with the fish liver oil (pen 9). The diet containing the unextracted leaf meal (pen 2) produced the deepest shank pigmentation.

Run 3.—Effects of Various Concentrations of Broccoli Leaf Meal in Broiler Rations

An experiment designed to show the effects of different concentrations of broccoli leaf meal in broiler rations was started in June 1944. The meal was similar to that used in run 1.

PROCEDURE

Forty 1-day-old, New Hampshire, male chicks, divided into two groups of 20 birds each, were fed each diet. Table 34 shows the formula for the basal diet. Table 35 shows the concentrations of the broccoli leaf meal used and the calculated analyses of the diets. Since white corn was used in these experiments, the carotene in the broccoli meal was the only source of vitamin A.

Table 34.—*Formula for basal diet in run 3*

Ingredients	Percent	Ingredients	Percent
Ground white corn	15	Steamed bone meal	1
Ground oats	15	Oystershell flour	1.5
Wheat bran	15	Salt mix [1]	.5
Cracked wheat	27	D-activated animal sterol [2]	.075
Soybean oil meal	20		
Meat scrap	5	Total	100.075

[1] A mixture of 100 pounds of salt and 2 pounds of anhydrous manganous sulfate.
[2] Contained 2,000 I. U. of vitamin D per gram.

RESULTS

From the average weights of the birds at 3, 6, and 9 weeks (table 35), it is apparent that extremely small percentages of broccoli leaf meal are effective in broiler rations. One and one-half percent appeared to supply all the factors necessary for excellent growth. One half of 1 percent was inadequate when used alone but produced excellent growth when supplemented with distiller's solubles to supply additional riboflavin, indicating that 0.5 percent broccoli leaf meal supplied all the vitamin A needed but was somewhat low in riboflavin and possibly other B vitamins.

Thirty percent of broccoli leaf meal in a special diet produced inferior growth. This was expected, but the experiment was tried to determine how great a concentration of vegetable leaf meal could be

TABLE 35.—*Calculated analyses of diets in run 3 and results of feeding tests at end of 3, 6, and 9 weeks*

Pen No.	Diet	Analyses of diet			Average weight of birds at—		
		Protein	Riboflavin	Vitamin A	3 weeks	6 weeks	9 weeks
		Percent	*Micrograms per pound*	*International Units per pound*	*Pounds*	*Pounds*	*Pounds*
1	Basal	19. 83	687	----------	0. 293	0. 93	(1)
2	Basal+0.5 percent broccoli leaf meal	20. 00	740	1, 421	. 399	1. 04	1. 75
3	Basal+1.5 percent broccoli leaf meal	20. 04	836	4, 263	. 418	1. 13	1. 99
4	Basal+6 percent broccoli leaf meal	20. 69	1, 282	17, 054	. 394	1. 07	1. 94
5	Basal+10 percent broccoli leaf meal	21. 24	1, 680	28, 431	. 386	1. 03	1. 83
6	Special basal [2]+30 percent broccoli leaf meal	20. 35	3, 549	85, 295	. 317	. 90	1. 58
7	Diet for pen 2+0.5 percent of distiller's solubles [3]	20. 14	1, 282	1, 421	. 441	1. 11	1. 92
8	Diet for pen 3+0.39 percent of distiller's solubles	20. 17	1, 282	4, 263	. 425	1. 13	2. 00
9	Basal+6 percent alfalfa meal	19. 84	1, 066	3, 937	. 383	1. 07	1. 83

[1] Half the birds were dead.
[2] This was the same as the regular basal diet except that soybean oil meal was omitted.
[3] Contained 250 micrograms of riboflavin per gram.

tolerated. The birds were all active, however, and had a healthy appearance.

As in run 1, there was a progressive increase in pigmentation of the shanks with increasing broccoli concentration, probably owing to the high xanthophyll content of the broccoli. The color of the shanks of birds fed 10 and 30 percent broccoli leaf meal was such an intense orange that it could not be graded by ordinary standards. Plate 1 shows the pigmentation produced by feeding alfalfa meal and various levels of broccoli leaf meal.

Organoleptic tests were made on this series of birds. The meat of the birds fed 30 percent broccoli leaf meal was highly pigmented and of strong flavor. It was liked by one of the group but was considered too strong by the others. The birds fed 10 percent were highly flavored also but were liked by most of the group. Birds fed lower concentrations of the meal were preferred by one individual but were classified in general as just good chicken. This test was made because some of the birds used in the preliminary trials had been sold as broilers, and the exceptional flavor of the broccoli-fed birds had led to requests for more of this type of poultry.

Run 4.—Broccoli Leaf Meal as a Substitute for Alfalfa Meal in Commercial Broiler Rations

Since broccoli leaf meal had proved an excellent substitute for alfalfa meal in battery tests, an experiment was designed to evaluate this meal in a diet fed to broilers under commercial conditions. The value of crystalline riboflavin in supplementing 1 percent of broccoli leaf meal was also determined. A detailed description of these tests has been published (*15*).

PROCEDURE

Five hundred Barred Cross 1-day-old chicks started in each of four 15- by 24-foot pens in a long broiler house were used for these tests. There were one coal stove and other appropriate equipment for each pen. The management of the pens was as identical as possible. Only water was offered besides the mash, except that when the chicks were 34 days old 0.05 percent sulfaguanidine was added to the diet and fed for 7 days. This treatment was given also at the first sign of cecal coccidiosis, and was effective in controlling it, inasmuch as mortality was negligible.

When such a large number of chicks are used in tests under commercial conditions, it is not practical to weigh them weekly. In this experiment, the weight of the lot was taken only at the end of the experiment, when the broilers were 13 weeks of age.

Table 36 shows the basal diet, and table 37 shows the leaf meal supplements and the analyses of the four diets fed, one of which was a commercial broiler mash.

TABLE 36.—*Formula for basal diet in run 4*

Ingredients	Percent	Ingredients	Percent
Ground yellow corn	30	Steamed bone meal	1
Ground oats	15	Oystershell flour	1.5
Wheat bran	15	Salt mix [1]	.5
Cracked wheat	12	D-activated animal sterol [2]	.075
Soybean oil meal	15		
Corn gluten meal	5	Total	100.075
Fish meal	5		

[1] A mixture of 100 pounds of salt and 2 pounds of anhydrous manganous sulfate.
[2] Contained 2,000 I. U. of vitamin D per gram.

RESULTS

Table 37 gives the results of the feeding tests at the end of 13 weeks. Mortality was highest in pen 4, the lot fed the commercial broiler mash. Three percent of this mortality occurred between the sixth and eighth weeks of the test and was diagnosed as a mild attack of intestinal coccidiosis. The other pens had low mortality during this period, even though all groups were confined in the same house. The commercial diet caused the birds to have very "sticky" droppings, and the litter caked over before it did in the other pens. Possibly this wet "sticky" litter provided a more favorable environment for the development of coccidia.

As measured by rate of growth of the birds and pounds of feed consumed per pound of gain in weight, 1 percent of broccoli leaf meal supplemented by crystalline riboflavin was superior to either 5 percent of alfalfa meal or 1 percent of broccoli leaf meal. This diet (basal diet plus 1 percent broccoli leaf meal plus crystalline riboflavin) was also superior to the high-quality commercial broiler mash.

RUN 5.—SPINACH, RHUBARB, PEA VINE, AND BEET LEAF MEALS IN BROILER RATIONS

Run 5 was designed to determine the value of several leaf meals not previously tested and to determine whether the pea vine meal prepared in 1944 was more satisfactory as a feed supplement than the meal prepared in 1943.

The experiment was of special interest because three of the leaf meals—spinach, rhubarb, and beet—had a high content of free oxalic acid (table 38).

PROCEDURE

This was a battery test similar to run 3. Forty 1-day-old chicks in 20-chick groups were used for each test. The basal diet was the same as that used in run 3. Table 39 shows the analyses of the diets.

TABLE 37.—*Analyses of diets in run 4 and results of feeding tests at end of 13 weeks*

Pen No.	Diet	Analyses of diet					Mortality of birds	Average weight of birds	Feed consumed per pound of gain in weight of birds
		Protein	Crude fiber	Ether extract	Riboflavin	Carotene as vitamin A			
		Percent	*Percent*	*Percent*	*Micrograms per pound* [1]	*International Units per pound*	*Percent*	*Pounds* [2]	*Pounds*
1	Basal+5 percent alfalfa meal	21. 1	5. 65	4. 42	1, 122	4, 244	6. 6	2. 70	4. 31
2	Basal+1 percent broccoli leaf meal	20. 8	5. 47	4. 26	919	3, 790	7. 0	2. 84	4. 24
3	Basal+1 percent broccoli leaf meal+crystalline riboflavin	20. 5	5. 26	4. 45	2, 119	4, 167	5. 2	3. 17	3. 82
4	High-quality commercial broiler mash	24. 3	6. 57	6. 05	1, 634	5, 911	9. 6	3. 07	3. 84

[1] Calculated values.
[2] Weighted average—assuming a 50–50 distribution between males and females.

TABLE 38.—*Oxalic acid content of leaf meals and mashes made from spinach, rhubarb, and beets*

Vegetable	Oxalic acid content of—	
	Leaf meal	Mash
	Percent	*Percent*
Spinach	3. 68	0. 092
Rhubarb	5. 27	. 200
Beets	11. 19	. 279

RESULTS

Table 39 shows the average weights of the birds at the end of 5 weeks and again after 10 weeks. It is apparent that all three leaf meals containing free oxalic acid were equal to or better than alfalfa meal as growth supplements. No toxic effects could be observed in any of the birds.[10] Spinach and beet leaf meals at a 2.5-percent level were definitely superior to 5 percent of alfalfa meal.

The weight of the birds fed pea vine meal was slightly superior at 10 weeks to that of the birds fed the same percentage of alfalfa meal. Because of better storage conditions, the carotene value of this pea vine meal was greater than that of the meal prepared in 1943. This probably accounted for the better results in this run.

RUN 6.—KALE, MIXED PEA VINE AND LIMA BEAN VINE, AND SUPPLEMENTED BROCCOLI LEAF MEALS IN BROILER RATIONS

In December 1944, tests were made to determine the value of kale leaf meal and a mixture of pea vine and lima bean vine meals in supplementing broiler rations. Since a diet containing 1 percent broccoli leaf meal supplemented with crystalline riboflavin produced excellent birds in run 4 (table 37), tests were made to determine the relative efficiency of this low level of broccoli when supplemented with crystalline riboflavin in one case and distiller's solubles in another.

PROCEDURE

Approximately 590 crossbred chicks in each of four 15- by 24-foot pens were fed the diets for 14 weeks. Each pen was provided with a coal-burning brooder stove and the usual equipment required for growing chicks.

The basal diet was the same as that used in run 4 (table 36). Table 40 shows the supplements added and the calculated analyses of the diets.

[10] Since the completion of this manuscript, Robertson, Brin, and Norris have reported that beet leaves have no injurious effects when fed to chicks. (See ROBERTSON, E. I., BRIN, M., and NORRIS, L. C. THE USE OF DEHYDRATED BEET LEAVES IN CHICK RATIONS. Poultry Sci. 26: 582–587, illus. 1947.)

TABLE 39.—*Analyses of diets in run 5 and results of feeding tests at end of 5 and 10 weeks*

Pen No.	Diet	Analyses of diet					Average weight of birds at—	
		Protein	Crude fiber	Ether extract	Riboflavin	Carotene as vitamin A	5 weeks	10 weeks
		Percent	*Percent*	*Percent*	*Micrograms per pound*	*International Units per pound*	*Pounds*	*Pounds*
1	Basal+2.5 percent spinach leaf meal	23. 6	5. 4	5. 02	750	8, 650	0. 513	2. 13
2	Basal+3.8 percent rhubarb leaf meal	23. 6	4. 95	4. 59	1, 045	10, 620	. 450	1. 87
3	Basal+5 percent pea vine meal	22. 9	5. 89	7. 58	772	2, 580	. 440	2. 00
4	Basal+2.5 percent beet leaf meal	23. 9	4. 74	7. 23	705	4, 560	. 565	2. 12
5	Basal+5 percent alfalfa meal	23. 0	6. 30	6. 37	908	1, 820	. 453	1. 84

TABLE 40.—*Calculated analyses of diets in run 6 and results of feeding tests at end of 14 weeks*

Pen No.	Diet	Analyses of diet					Mortality of birds	Average weight of birds	Feed consumed per pound of gain in weight of birds
		Protein	Crude fiber	Ether extract	Riboflavin	Carotene as vitamin A			
		Percent	*Percent*	*Percent*	*Micrograms per pound*	*International Units per pound*	*Percent*	*Pounds*	*Pounds*
1	Basal+1.5 percent kale leaf meal	20. 9	4. 8	3. 6	954	4, 230	4. 4	2. 97	4. 07
2	Basal+2.5 percent pea vine meal+2.5 percent lima bean vine meal	20. 5	4. 7	4. 2	1, 017	3, 940	5. 1	2. 92	4. 30
3	Basal+1 percent broccoli leaf meal+1 percent distiller's solubles	20. 5	5. 2	4. 4	2, 084	3, 260	4. 4	3. 04	4. 06
4	Basal+1 percent broccoli leaf meal+crystalline riboflavin	20. 5	5. 2	4. 4	2, 060	3, 260	4. 1	2. 88	4. 23

RESULTS

Table 40 gives the results of these feeding tests at the end of 14 weeks. Both the kale leaf meal and the mixture of pea vine and lima bean vine meals produced excellent growth, although the kale leaf meal was utilized with slightly greater efficiency. Somewhat better growth and more efficient utilization of feed resulted when 1 percent of broccoli leaf meal was supplemented with riboflavin in distiller's solubles than when it was supplemented with an equal amount of riboflavin in the crystalline form.

Run 7.—Broccoli Leaf Meal in Laying and Breeding Rations[9]

The feeding tests described in the foregoing six runs had shown that broccoli leaf meal in low concentrations could be used successfully in the rations of growing chicks to replace alfalfa meal at higher concentrations. In this run, the use of broccoli meal in commercial laying and breeding rations was tested.

PROCEDURE

In these tests, the basal mash (table 41) was supplemented with broccoli leaf meal, alfalfa meal, and fish liver oil as shown in table 42. Table 42 also shows the analyses of the mashes and of the scratch feed, which was fed as 50 percent of the diets.

Table 41.—*Formula for the basal laying and breeding mash in run 7*

Ingredients	Percent	Ingredients	Percent
Corn meal	20	Molasses	2.5
Ground barley	10	Gluten meal	2.5
Bran	7.5	Lay mix [1]	1.25
Ground wheat	20	Salt	1
Ground oats	7.5	Fine oystershell	3
Fish meal	10		
Meat scraps	5	Total	97.75
Soybean oil meal	7.5		

[1] A mixture of cod liver oil, Delsterol, and vitamin B complex.

The test was started on September 20, 1944, and carried on for 3 months. The New Hampshire hens used in the laying experiments were hatched on January 5, 1944, and had been laying at a good rate since June 1. The White Leghorn hens in pens 6 and 7 were hatched on January 5, 1944, and had started laying heavily on June 15. The birds in pen 8 were hatched on February 15 and had a good laying record before the experiment.

[9] These tests were conducted by Cecil J. Toor, owner of the Sandy Ridge Poultry Farm, Doylestown, Pa.

TABLE 42.—*Analyses of laying and breeding mashes in run 7*[1]

Mash	Analyses of mash				Vitamin A		
	Protein	Crude fiber	Ether extract	Riboflavin	From carotene in leaf meal	Calculated from vitamin A in fish liver oil	Total
	Percent	*Percent*	*Percent*	*Micrograms per pound*	*International Units per pound*	*International Units per pound*	*International Units per pound*
Laying:							
Basal + 2½ percent of broccoli leaf meal	23. 5	4. 2	5. 0	1, 250	7, 615	----------	7, 615
Basal + 5 percent of alfalfa meal + 4 pounds of fortified cod liver oil[2] per ton of mash	20. 7	4. 1	5. 25	817	1, 650	3, 632	5, 282
Breeding:							
Basal + 2½ percent of broccoli leaf meal + 4 pounds of fortified cod liver oil[2] per ton of mash	23. 6	5. 1	5. 91	2, 270	6, 760	3, 632	10, 392
Basal + 5 percent of alfalfa meal + 8 pounds of fortified cod liver oil[2] per ton of mash	23. 2	5. 2	5. 78	2, 200	2, 350	7, 264	9, 614

[1] Scratch feed fed as 50 percent of the diet contained 12.3 percent protein, 3.34 percent crude fiber, 3.76 percent ether extract, and 7.25 micrograms of riboflavin per gram.

[2] 800 I. U. of vitamin D and 4,000 I. U. of vitamin A per gram.

The 95-day egg production of these birds, together with other pertinent data, are shown in table 43. Table 44 shows the hatching record of six lots of eggs produced by birds fed each mash.

TABLE 43.—*Eggs produced in 95 days by chickens fed diets supplemented with alfalfa and broccoli leaf meals*

Pen No.	Leaf meal supplement	Breed of birds	Birds at start	Mortality of birds	Eggs produced	Average eggs produced per bird
			Number	*Percent*	*Number*	*Number*
1	Broccoli	New Hampshire	100	0	5, 442	55. 2
2	do		[1] 100	2	5, 860	59. 3
3	do		100	5	5, 520	56. 1
4	Alfalfa		[2] 100	2	4, 985	50. 6
5	do		100	2	5, 011	50. 8
6	Broccoli	White Leghorn	125	2	7, 874	63. 4
7	do		125	4	6, 552	53. 1
8	Alfalfa		120	6	6, 209	52. 9

[1] 2 broody birds withdrawn.
[2] 1 broody bird withdrawn.

TABLE 44.—*Hatchability of eggs produced by chickens fed diets supplemented with alfalfa and broccoli leaf meals*

Lot No.	Leaf meal supplement	Eggs set	Unfertile eggs after 18 days	Eggs hatched	
		Number	*Number*	*Number*	*Percent*
1	Broccoli	180	24	137	76. 1
	Alfalfa	360	53	265	73. 6
2	Broccoli	540	79	402	74. 4
	Alfalfa	540	86	391	72. 4
3	Broccoli	1, 440	145	1, 187	82
	Alfalfa	900	101	731	81
4	Broccoli	1, 080	128	875	81
	Alfalfa	900	96	723	80
5	Broccoli	1, 260	132	1, 034	82
	Alfalfa	1, 440	154	1, 205	83
6	Broccoli	1, 260	177	1, 064	82
	Alfalfa	1, 440	211	1, 153	80
Total or average	Broccoli	5, 760	685	4, 693	81. 4
	Alfalfa	5, 580	701	4, 468	80. 0

The average egg production was somewhat greater for the birds fed the broccoli leaf meal than for those fed the alfalfa meal. Since only 2½ percent of broccoli leaf meal was used in the broccoli mash, whereas 5 percent of alfalfa meal plus fish liver oil was used in the alfalfa mash, it appears that broccoli leaf meal could be used to advantage in laying mashes.

Hatching results also indicated satisfactory use of broccoli meal in a breeding mash. One advantage in the use of the broccoli meal for the breeding mash would lie in its high vitamin A value in winter and spring, when good-grade alfalfa meal is seldom available.

CHAPTER 5

CAROTENE CONCENTRATES AND OTHER LIPID PRODUCTS IN VEGETABLE LEAF MEALS

By Monroe E. Wall, *chemist*

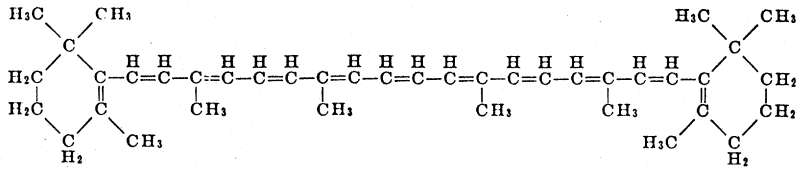
Leaves contain a large number of chemically and physiologically diverse compounds which for brevity are here called lipids. They have one property in common—they are soluble in materials such as acetone, benzene, chloroform, ether, and petroleum ether, and insoluble in water. The vegetable leaf meals studied in this investigation contain from 2.5 to 9 percent of lipids.

On the basis of their reactivity with alkali, lipids may be classified as saponifiable and unsaponifiable. Among the compounds in the first group are the chlorophylls, phospholipids, and triglycerides. The unsaponifiable group includes carotene, xanthophyll, tocopherol, vitamin K, sterol, and hydrocarbons.

Carotene

DESCRIPTION AND PROPERTIES

Carotene is an orange-red pigment contained in all green leaves in concentrations of 0.02 to 0.1 percent (dry basis).. It is an important plant constituent, being one of the chief sources of vitamin A for poultry, stock animals, and man. The compound was first isolated from carrots by Wackenroder in 1831. It was not prepared in pure form, however, until 1907. Its formula, $C_{40}H_{56}$, was established by the outstanding work of Willstätter and Stoll (*49*). Carotene is highly unsaturated and easily oxidized, and is unstable in the presence of light. A number of isomers—α-, β-, and γ-carotene—have been found in nature. β-Carotene, the most important, is the predominant carotene of leaf meals. Its structure was established by Karrer and Morf (*19*) in 1931.



The conversion of β-carotene to vitamin A in vivo was first demonstrated by Moore (*23*), who showed that it is split in the liver, forming two molecules of vitamin A. Only carotenoids that contain the β-carotene grouping can form vitamin A.

Carotene is used commercially as a bland source of vitamin A. It is sold usually in solution in vegetable oils. The demand for the pure crystalline compound is limited. Until recently the product prepared as a concentrate could not compete with vitamin A from fish-liver oils on a price basis, but improved sources and production methods have altered this situation.

PREVIOUS METHODS FOR RECOVERY

A number of procedures for the extraction and preparation of carotene have appeared in the literature. Many of them deal with the isolation of crystalline carotene and are not concerned with yields or costs. A few of the better known methods will be briefly described.

Willstätter and Stoll (*49*): Carotene is obtained as a byproduct in the processing of leaf meal for chlorophyll. The pigments are extracted with 80-percent acetone and transferred to petroleum ether, which is washed with 80-percent methanol to remove xanthophyll, and then repeatedly washed with water to remove all the acetone and methanol. The chlorophyll precipitates and is removed by filtration. The carotene is precipitated from the concentrated petroleum ether solution by 95-percent alcohol. This method of extraction and precipitation gives relatively poor yields.

Holmes and Leicester (*16*): A paste is made by mixing leaf meal with 3 N sodium hydroxide, converting chlorophyll to a water-soluble form. After standing for 24 hours, the paste is diluted with water and extracted with chloroform. The chloroform is removed by evaporation, and the residue dissolved in petroleum ether. Xanthophyll is removed with aqueous methanol, and the carotene is precipitated from the concentrated petroleum ether. There are two drawbacks to this method—the residual meal is rendered worthless by the alkali treatment, and chloroform is too expensive to use on a large scale.

Schertz (*35*): The leaf meal is extracted with petroleum ether, and the extract is shaken repeatedly with a solution of potassium hydroxide in methanol to remove chlorophyll. The remainder of the procedure is similar to that of Willstätter and Stoll.

Morgal, Petering, and Miller (*24*): The leaf meal is extracted with acetone; the resultant solution is made to 85-percent acetone by the addition of water and then refluxed with barium hydroxide octahydrate. The chlorophyll is thus saponified and converted to an insoluble barium salt, which is removed by filtration. The acetone filtrate is concentrated to 50-percent acetone, at which point the lipidal material, including carotene and xanthophyll, precipitates. The precipitate is filtered and dissolved with petroleum ether. From this point, the purification of carotene follows conventional lines.

EXTRACTION

Carotene has been extracted from plant material with a large number of organic solvents. The solvents tested here included three petroleum ethers [11] having the boiling points 35° to 59°, 63° to 70°, and 88° to 98° C., respectively, and acetone, chloroform, trichloroethylene, and carbon tetrachloride. All extracted large proportions of other plant pigments and lipids along with the carotene. The quantities and types of these contaminants varied widely, depending on the solvent used.

The quantities of carotene, xanthophyll, and chlorophyll extracted by the various solvents in 5 hours were determined (table 45). The

[11] These petroleum ethers will henceforth be designated as PE 1, PE 2, and PE 3, respectively.

quantities varied widely, depending on the solvent used. PE 1 extracted about three times as much chlorophyll as carotene. The others extracted greater proportions of chlorophyll; approximately 20 times as much chlorophyll as carotene was obtained with acetone and trichloroethylene.

TABLE 45.—*Pigment composition of broccoli leaf meal extracts prepared with various solvents*

Solvent	Carotene	Xanthophyll	Chlorophyll
	Milligrams	*Milligrams*	*Milligrams*
PE 1	264	355	840
PE 2	267	450	1, 045
PE 3	250	660	1, 400
Acetone	252	303	4, 260
Trichloroethylene	274	798	4, 650

It has been reported that petroleum ether will not extract either chlorophyll or xanthophyll from plant material (*35, 49*). However, appreciable quantities of both chlorophyll and xanthophyll were extracted from the various leaf meals with a wide range of petroleum ethers. Although pure xanthophyll and chlorophyll are only slightly soluble in low-boiling petroleum ether, the solubilities of these compounds seem to be markedly affected by other fat-soluble substances in plant material.

The rate of extraction of carotene from broccoli leaf meal by different solvents was determined in a Soxhlet apparatus of 1-pound capacity. The results are shown in table 46. All the solvents extracted 100 percent of the carotene in 4 to 5 hours. PE 2 and PE 3 and trichloroethylene extracted approximately 90 percent in 1 hour; PE 1 and acetone extracted it somewhat less rapidly.

TABLE 46.—*Rate of extraction of carotene from broccoli leaf meal with various solvents*

Time (hours)	Percent of total carotene extracted in—				
	PE 1	PE 2	PE 3	Acetone	Trichloroethylene
1	77. 5	89. 0	90. 5	83. 0	93. 0
2	86. 0	95. 0	93. 0	91. 5	94. 0
3	90. 0	100. 0	95. 0	100. 0	99. 5
4	100. 0	100. 0	97. 5	100. 0	98. 0
5	100. 0	100. 0	100. 0	100. 0	100. 0

The petroleum ethers are most suitable for extraction of carotene, owing to their low cost, chemical inertness, and the fact that they extract less of the pigment impurities. They are used almost exclusively for industrial carotene extraction. A commercial fraction, PE 2, was used for the most part in these experiments.

In the laboratory, carotene may be extracted conveniently in percolators or Soxhlet extractors. Figure 29 shows a large laboratory

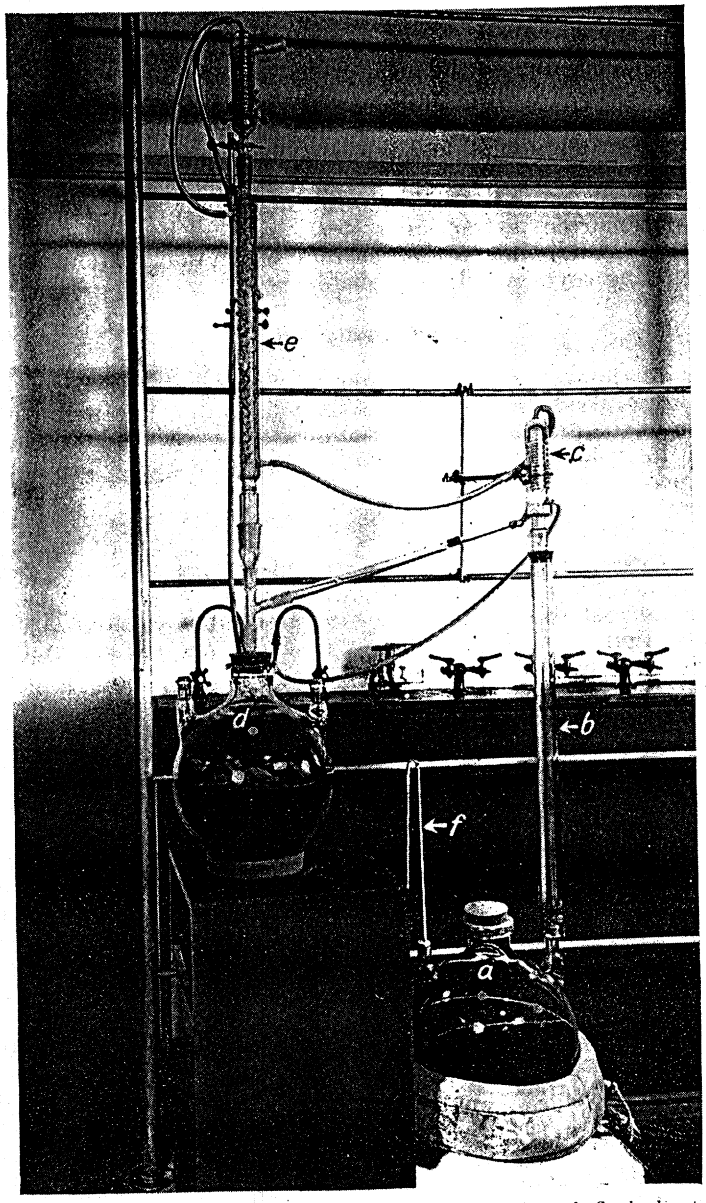


FIGURE 29.—Soxhlet extractor. *a*, 22-liter Pyrex glass 3-neck flask, heated with Glass-col 22-liter hemispherical mantle or an internal steam coil; *b*, condenser, used with either steam or cold water; *c*, Friedrich condenser (Pyrex 3440); *d*, 3-neck, Pyrex glass, 22-liter flask with tubulature at bottom; *e*, several auxiliary condensers; *f*, siphon tube attached to flask *a* and tubulature of flask *d*.

Soxhlet extractor with a capacity of 4.5 kg. (10 pounds). In preparing the leaf meal for extraction, a compromise must be made between fine grinding of the meal, which gives highest extraction, and coarse grinding, which permits freer passage of the solvent through the meal. A meal of 20- to 40-mesh represents the best compromise for laboratory manipulations.

Industrially, extraction processes are conducted in a number of ways. Percolation, stirring the meal into a slurry with the solvent, and countercurrent extraction systems have all been used. From a theoretical standpoint, countercurrent extraction, extensively used for preparing soybean oil, is probably best.

PURIFICATION

Most of the data on purification presented here are based on the procedure of Wall, Kelley, and Willaman (*46*). The pigment composition of the hexane extracts from leaf meals rich in carotene averages 15 to 20 percent carotene, 20 to 25 percent xanthophyll, and 55 to 65 percent chlorophyll. To obtain an attractive product, it is necessary to remove the chlorophyll. This may be done by adsorption or by saponification methods. Preliminary experiments proved that an excessive quantity of various adsorbents would be required for this purpose, and hence saponification procedures were tried.

Although chlorophyll may be separated from carotene by direct saponification of the plant material, according to the method of Holmes and Leicester (*16*), or by methods based on the classical Willstätter-Stoll procedure (*49*), such methods are time consuming and do not lend themselves to commercial practice. Therefore, saponification of chlorophyll in the petroleum ether extract was attempted.

It was found that 95-percent ethanol containing 5 percent of potassium hydroxide, or saturated with sodium hydroxide, was completely miscible with petroleum ether, and when a petroleum ether plant extract was mixed with the alcoholic potassium hydroxide and boiled, most of the chlorophyll was rapidly saponified. The combination of 5 percent of potassium hydroxide or saturated solution of sodium hydroxide in 95-percent ethanol, 0.5-hour reflux time, and a 1:4 ratio of alcohol to PE 2 was selected as most economical and effective.

The following rapid and simple method was developed. In certain respects, it is similar to the analytical procedure of Kuhn and Brockmann (*20*). The concentrated PE 2 extract (3 to 4 liters) from 4.5 kilograms of leaf meal is mixed with 1 liter of 95-percent ethanol containing 5 percent of potassium hydroxide. The mixture is vigorously refluxed for 0.5 hour and then cooled. Sufficient water (187.5 ml.) is added to make the final alcohol concentration 80 percent. The extract is shaken and then allowed to stand for about 15 minutes. Two layers are formed. The lower consists of the aqueous alcohol with dissolved saponification products and also some xanthophyll; the upper consists of the PE 2 extract, from which most of the chlorophyll and some xanthophyll have been removed. Since the aqueous alcohol layer contains little carotene, it is set aside for recovery of the alcohol. A 6-liter separatory funnel, well illuminated, is used to separate the two layers.

At this stage, the petroleum ether extract is usually dark brown, probably owing to small amounts of unsaponified chlorophyll remaining in solution. It is wet and contains traces of alkali, but the subsequent treatment renders any drying or removal of alkali unnecessary.

Table 47 shows the percentage of chlorophyll remaining after saponification of an extract of broccoli leaf meal. The saponified extract was subjected to a continuous 80-percent ethanol extraction, after which the extract was twice resaponified. The first saponification removed about 96 percent of the chlorophyll; subsequent treatment with alcohol removed an additional 2 to 3 percent, which probably had been emulsified in the petroleum ether solvent. Two further saponifications failed to remove the remaining 1 percent. This remnant was probably a decomposition product. The last two extracts obtained by the various treatments were dark brown, owing to the fact that the remaining 1 percent of chlorophyll or its decomposition products constituted from 5 to 10 percent of the total pigment.

TABLE 47.—*Effect of saponification on chlorophyll in petroleum ether extract of broccoli leaf meal*

Treatment	Chlorophyll content after treatment		
	Milligrams per kilogram of leaf meal	*Percent of original chlorophyll content*	*Percent of total pigment*
Original extraction	2, 640	100. 0	74. 5
First saponification	111	4. 2	15. 3
Continuous 80-percent ethanol extraction	43	1. 6	10. 5
Second saponification	34	1. 3	7. 2
Third saponification	34	1. 3	7. 2

After saponification and separation of the saponification products, the extract may be used to prepare a crude concentrate. In order to obtain more refined products, the solution must be freed of the residual chlorophyll and xanthophyll. This can be accomplished by adsorption, liquid extraction methods, or combinations of these processes.

The ideal adsorbent should remove contaminating pigments efficiently without destroying or retaining carotene. Highly acidic or basic compounds and most carbon blacks are unsuitable for this purpose. Activated magnesia No. 2641 [12] and activated alumina are excellent adsorbents, but hydrated lime is more suitable for large-scale work. It is about one-sixth as active as activated magnesia No. 2641, but costs only one-fiftieth as much. Moreover, hydrated limes [13] that were specially prepared for this work had one-half the activity of the magnesia adsorbent. These lime products could be produced at a cost but little higher than ordinary hydrated lime.

A number of commercial hydrated limes were tested. All removed the remaining chlorophyll and variable proportions of xanthophyll

[12] This may be obtained from the Westvaco Chlorine Products Co., Newark, Calif.

[13] Prepared by the Warner Co., Devault, Pa.

from the saponified extracts. It is not practical to remove all the xanthophyll, since this requires an inordinately large quantity of lime. Moreover, the product can be made xanthophyll-free economically by further treatment with 80- to 85-percent ethanol. For many purposes, the xanthophyll in the extracts is not objectionable.

The following example illustrates the use of hydrated lime: A 4-liter concentrate of a saponified extract of 4.5 kg. of leaf meal was thoroughly stirred with 1.0 to 2.0 kg. of commercial hydrated lime and filtered. The filter cake was thoroughly washed three or four times with 6 to 8 liters of PE 2. A deep-red solution was obtained, in which 70 to 80 percent of the total pigment was carotene and 30 to 20 percent xanthophyll. The yield of carotene was from 85 to 95 percent of that originally present in the crude extract. The analytical data of a typical experiment are shown in table 48.

TABLE 48.—*Recovery and purification of carotene from petroleum ether extract of broccoli leaf meal*

Treatment	Content after treatment					
	Carotene		Xanthophyll		Chlorophyll	
	Milligrams per kilogram of leaf meal	*Percent of total pigment*	*Milligrams per kilogram of leaf meal*	*Percent of total pigment*	*Milligrams per kilogram of leaf meal*	*Percent of total pigment*
Original extraction	480	13. 4	493	13. 8	2, 600	62. 8
Saponification	463	53. 1	274	31. 4	133	15. 5
Adsorption on lime, 2,000 gm.	432	74. 0	152	26. 0	Trace	0

Saponification followed by lime adsorption removed about half the plant lipids in a PE 2 extract of broccoli leaf meal. About 0.45–0.56 gm. of carotene in 20 gm. of plant lipids was obtained per kilogram of meal.

The saponified extract may also be purified by liquid extraction before or after the lime treatment. A continuous extractor of a type used for extracting light liquids with heavier ones was devised for this purpose. Aqueous ethanol of approximately 60-percent concentration is boiled, and the vapors (80- to 85-percent ethanol) are condensed, passed through a tall column of petroleum ether extract, and returned to the boiling flask. When a saponified PE 2 solution was thus extracted, a solution was obtained in which 85 to 90 percent of the total pigment was carotene and the remainder was xanthophyll and unsaponified chlorophyll. There was little loss of carotene in this operation. The extract was dark brown, as contrasted with the clear, deep-red extracts obtained by the adsorption technique. Such a carotene concentrate may have uses for which the color is not objectionable.

Purification by layering was also investigated. Petroleum ether extracts were shaken in separatory funnels with 80- to 85-percent ethanol. Various ratios of alcohol to petroleum ether were tested. The higher the ratio of alcohol to petroleum ether, the more rapid was the removal of alcohol-soluble impurities. As in the liquid-

liquid extractor, a dark-brown carotene extract was obtained, in which 85 to 90 percent of the total pigment was carotene.

Similarly, extracts containing xanthophyll but no chlorophyll after adsorption were purified by the alcohol treatment. Such a procedure is practical only when a pure carotene extract is desired.

Carotene concentrates of different degrees of purity may be prepared for specific markets by the procedures outlined. Table 49 summarizes the methods used and the pigment composition of the extracts prepared.

The product obtained in method 1 by saponification only was a crude extract, partly purified in respect to xanthophyll and chlorophyll. The extract freed of solvent might be suitable for a crude feed supplement for animals. When this extract was treated with lime (method 2), a deep-red concentrate free of chlorophyll was formed. This concentrate contained 18,000 to 24,000 μg of carotene (30,000 to 40,000 I. U. of vitamin A) per gram of concentrate. It was easily soluble in vegetable oils, and might be suitable for a food or feed supplement. Treating the saponified extract with 80- to 85-percent ethanol or 90-percent methanol produced a concentrate which contained relatively less of pigment impurities than the concentrate from method 2. Owing to the presence of a small amount of chlorophyll or its degradation products, this concentrate was brown instead of red, which is the color of a typical carotene concentrate. It would probably be acceptable for uses for which an off-color is not objectionable. The concentrate from method 4, resulting from the further treatment of that from method 2 with 80- to 85-percent ethanol or 90-percent methanol, yielded a carotene preparation free of xanthophyll and chlorophyll. The concentrates from methods 1 to 4 had about the same pro vitamin A content, 18,000 to 24,000 μg (30,000 to 40,000 I. U. of vitamin A) per gram.

When the concentrate from method 2 was dissolved in petroleum ether and chilled, a copious precipitate of various lipidal substances was obtained. Most of the carotene remained in solution and was filtered off. In this way high-potency concentrates containing 97,000 to 108,000 μg of carotene (160,000 to 180,000 I. U. of vitamin A) per gram were obtained. Further treatment of this concentrate with a mixture of activated magnesia and Hyflo Super-Cel removed some impurities. The resulting oil contained 120,000 to 134,000 μg of carotene (200,000 to 222,000 I. U. of vitamin A) per gram. Crystalline carotene (melting at 171° to 173° C., corrected) was obtained from the concentrates from methods 5 and 6 by low-temperature crystallization.

STABILITY

Owing to its high degree of unsaturation, pure crystalline carotene is easily oxidized and must be stored in vacuum-sealed tubes. A study of the stability of oil solutions of carotene concentrates prepared from vegetable leaf meals has been made by Wall and Kelley (*44*). Table 50 shows the data obtained in a typical experiment with soybean oils. Carotene in oil solution becomes less stable with increased temperature and carotene concentrations. Oil solutions of the concentrate are more stable than oil solutions of the crystalline product, probably owing to the tocopherol in the carotene concentrates.

TABLE 49.—*Effects of various treatments on pigment composition of extracts from broccoli leaf meal*

Method No.	Treatment	Color of extract	Pigment composition			Vitamin A content [2]
			Carotene	Xanthophyll	Chlorophyll	
			Percent [1]	*Percent* [1]	*Percent* [1]	*International Units per gram of solids*
1	Petroleum ether extraction and saponification	Green-brown	50–60	20–30	10–20	30, 000–40, 000
2	Same as 1, plus lime treatment	Red	70–80	20–30	0	30, 000–40, 000
3	Same as 1, plus 80-percent ethanol extraction	Brown	80–90	5–10	5–10	30, 000–40, 000
4	Same as 2, plus 80-percent ethanol extraction	Red	100	0	0	30, 000–40, 000
5	Same as 2, plus removal of fats from PE 2 solution by chilling	do	95–100	0–5	0	160, 000–180, 000
6	Same as 5, plus adsorption on 1:1 activated magnesia and Hyflo Super-Cel	do	100	0	0	200, 000–220, 000
7	Crystallization of extract 6	do	100	0	0	1, 660, 000

[1] On basis of total pigment.
[2] Micrograms of carotene found by chemical analysis multiplied by conventional factor 1.66.

The type of vegetable oils used as a solvent has only slight effect on carotene stability. Crystalline carotene, however, is unstable in mineral oil, which contains no natural antioxidants.

TABLE 50.—*Retention of carotene in refined soybean oil after 6 months' storage*

Kind	Original concentration	Retention at—		
		5° C.	25° C.	37.5° C.
	Micrograms per gram	*Percent*	*Percent*	*Percent*
Concentrate	100	100	56	26
	1,000	100	22	11
	5,000	76	0	[1] 0
Crystalline	100	100	20	0
	1,000	100	16	[1] 0
	5,000	37	[2] 0	[3] 0

[1] At 5 months.
[2] At 2 months.
[3] At 1 month.

From the data in table 50, it is apparent that carotene in oil solution is most stable in cold storage and in concentrations of 100 to 1,000 μg per gram.

ANALYTICAL METHODS

During the investigation of methods for processing carotene, it was necessary to devise rapid methods for determination of the pigments. Since detailed descriptions of some of these procedures have been published (*43*, *45*), they will only be summarized here.

CAROTENE, XANTHOPHYLL, AND CHLOROPHYLL IN LEAF MEALS

The finely ground sample is extracted with acetone and filtered, and the acetone is made to volume. Chlorophyll is estimated directly in an aliquot portion by use of a photoelectric colorimeter at 660 mm. The method is essentially that of Petering, Wolman, and Hibbard (*30*). Another aliquot is taken for carotene and xanthophyll estimation. The acetone is diluted with water, the pigments are taken up in PE 2, and the solution is passed through an adsorption column consisting of 3 parts Hyflo Super-Cel and 1 part activated magnesia No. 2641. Carotene is eluted with 5-percent acetone in PE 2, and xanthophyll is washed out with 20- to 30-percent acetone in PE 2. Both pigments are estimated in a photoelectric colorimeter at 450 mm.

CAROTENE ONLY IN LEAF MEALS

The dry sample is extracted with 30-percent acetone in PE 2 and filtered. After removal of the acetone, the carotene is purified and estimated as described in the preceding paragraph.

CAROTENE, XANTHOPHYLL, AND CHLOROPHYLL IN FRESH MATERIAL

The sample is disintegrated and extracted with 30-percent PE 2 in absolute alcohol in a Waring Blendor. After filtration, the solution is

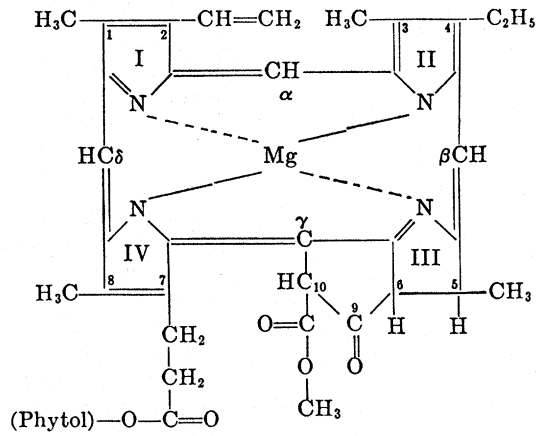
made to volume with alcohol. The pigments are then determined as described previously.

TOTAL SOLIDS IN PLANT EXTRACTS

In many cases it is desirable to know the total solids content of the extracts during various stages of purification. A 5-ml. aliquot of the extract, which should contain at least 25 mg. of solids, is pipetted into a weighed 10-ml. beaker. The solvent is evaporated slowly to dryness on a steam or hot-water bath. The beaker is then transferred to a vacuum oven at 50° C. and dried to constant weight.

CHLOROPHYLL

Chlorophyll is the pigment responsible for the green color of leaves, where it occurs in concentrations of 0.5 to 1.5 percent (dry basis). It is found in plants in two closely similar forms, chlorophyll a and chlorophyll b. The empirical formulas of the compounds, $C_{55}H_{72}O_5N_6Mg + \frac{1}{2} H_2O$ and $C_{55}H_{70}O_6N_4Mg$, respectively, were determined by Willstätter. The structure of chlorophyll may be represented as



Chlorophyll has some commercial use in soaps, cosmetics, and proprietary formulas, and has even been sold as a component of a household deodorizing product. It is marketed in two forms, oil soluble and water soluble, but it is usually mixed with oils or lanolin. Owing to difficulties of processing, it is rarely produced in pure crystalline form. Of late, increasing attention has been paid to its possible medicinal properties. It has been reported to be effective for the treatment of burns and trench mouth, and for suppurative diseases (*11*, *39*). The pharmaceutical use of chlorophyll, however, is still only in the experimental stage.

Practically all the procedures for extracting and isolating chlorophyll are based on the classical research of Willstätter and Stoll (*49*), who found that chlorophyll is easily extracted from leaf meals with aqueous acetone, methanol, or ethanol but is difficultly soluble in the anhydrous solvents. The best procedure involves extraction with 80-percent acetone. The pigments are then transferred to petroleum ether,

and xanthophyll is removed by washing with 80-percent methanol. The petroleum ether is washed with water until the last traces of acetone and methanol are removed. When this stage is reached, the chlorophyll is no longer soluble in petroleum ether and can be collected by filtration. The chlorophyll obtained in this manner is oil soluble.

Water-soluble chlorophyll (sodium or potassium magnesium isochlorophyllin) can be made by saponifying crude chlorophyll in methyl alcoholic potash. After dilution with water, salt is added until the chlorophyll derivative precipitates. The precipitate is filtered, washed with petroleum ether to remove oil-soluble impurities, and finally purified by repeated precipitation from methanol solution with ethanol.

In the procedure of Petering et al. (*29*), barium isochlorophyllin is formed as a crude precipitate. When this is treated with sodium carbonate, sodium magnesium isochlorophyllin is formed. After any insoluble salts are filtered out, the isochlorophyllin is "salted" out of solution and purified as outlined previously.

Another important chlorophyll derivative is pheophytin, an oil-soluble compound in which magnesium is replaced by hydrogen. Pheophytin is made by treating chlorophyll with alcoholic hydrochloric acid. Water-soluble pheophytin is prepared in the same manner as water-soluble chlorophyll. Such derivatives are termed phytochlorins or phytorhodins.

Phytol

A byproduct of the saponification of chlorophyll or pheophytin is phytol, $C_{20}H_{39}OH$. This compound, an aliphatic alcohol containing one unsaturated bond, is an oil boiling at 204° C. at 10 mm. It is used in the synthesis of vitamins E and K_1. Since it is fat soluble, it is easily separated from the water-soluble salt of chlorophyll and is then purified by removal of all the solvent, followed by distillation. Its structural formula is

$$CH_3-\underset{\displaystyle CH_3}{\underset{|}{CH}}-(CH_2)_3-\underset{\displaystyle CH_3}{\underset{|}{CH}}-(CH_2)_3-\underset{\displaystyle CH_3}{\underset{|}{CH}}-(CH_2)_3-\underset{\displaystyle CH_3}{\underset{|}{C}}=CH-CH_2OH$$

Xanthophyll

Xanthophyll, a member of the carotenoid family, is found in leaf meals in concentrations between 0.05 and 0.15 percent (dry basis). The compound differs from carotene in chemical structure in that it has two hydroxyl groups, one on each of the rings. It has no vitamin A activity. It is used commercially chiefly as a vegetable dye for food products.

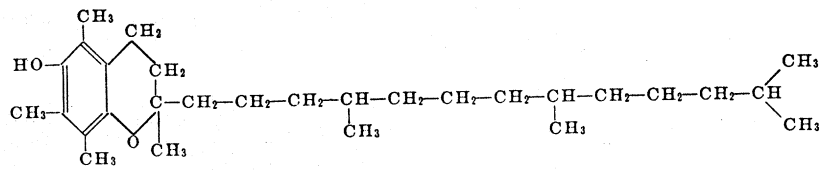
Xanthophyll is usually isolated as a byproduct in the processing of carotene or chlorophyll. It is separated rather easily from petroleum ether solutions containing a mixture of carotene, xanthophyll, and chlorophyll by treatment with 80- to 90-percent methanol or ethanol. The xanthophyll goes into the aqueous alcohol, while most of the other pigments remain in the petroleum ether. The xanthophyll is then extracted from the aqueous alcohol with ether, and finally

the ether is removed and the residue taken up in hot methanol. The product crystallizes on cooling.

A newer procedure is to adsorb a mixture of carotene, xanthophyll, and small quantities of chlorophyll on adsorbents such as activated magnesia No. 2641 or activated alumina. The carotene is washed out with 5-percent acetone in PE 2; the xanthophyll requires a mixture of 20- to 30-percent acetone in PE 2 for elution. After the acetone is washed out, the xanthophyll precipitates from the concentrated petroleum ether on cooling.

Tocopherol (Vitamin E)

Tocopherol is a yellow viscous oil. It is usually obtained from seed oils, but recent investigations at this Laboratory (*45*) have shown that vegetable leaf meals such as rhubarb and lima bean meals are good sources, containing between 0.5 and 1.0 mg. per gram (chap. 2). Tocopherol occurs in nature in three closely similar forms, designated α-, β-, and γ-tocopherol. α-Tocopherol is most common, but the proportion of this fraction in vegetable leaf meals is not yet known. α-Tocopherol has the empirical formula $C_{29}H_{50}O_2$. Its structure may be represented as



The β- and γ-compounds differ only in the number and position of methyl groups on the first ring.

The tocopherols are stable to heat but are easily oxidized to the quinone form. They are resistant to acid but are rather unstable in alkaline solution. The tocopherols are not only the antisterility vitamin, or vitamin E, but are also antioxidants. The α-form is twice as potent as the other two compounds in vitamin E efficacy, but all three are equally effective as antioxidants. The tocopherol quinones have neither vitamin E nor antioxidant properties.

Some preliminary experiments have been made in an effort to produce tocopherol concentrates from leaf meals. Two types of treatment have been used, one involving solvent fractionation, and the other high vacuum distillation. In both cases, the leaf meal is extracted with petroleum ether and saponified in petroleum ether with alcoholic potassium hydroxide at room temperature and in an atmosphere of hydrogen. Under these conditions, tocopherol loss due to alkali treatment is minimized. The alcohol and alkali are then washed out of the petroleum ether. Tocopherol may also be extracted from leaf meals with acetone. The solution is saponified with barium hydroxide and filtered, and finally the tocopherol as well as carotene is transferred to petroleum ether. The yield of tocopherol is practically quantitative, for the insoluble barium hydroxide does not oxidize the tocopherol as does soluble alkali. The reaction need not be conducted in an inert atmosphere.

In the solvent fractionation system, the purified petroleum ether solution is concentrated to a small volume, and 5 volumes of 96-percent methyl alcohol is added; the solution is cooled to −5° C., and the precipitate which forms is filtered and washed with 96-percent methanol. The residue is then dissolved in petroleum ether. The results in table 51 show that about 60 percent of the tocopherol goes into the methanol fraction, the concentration being increased from the original 1.6 to 3.6 percent. This treatment also fractionates the carotenoids, the main part of the carotene remaining in petroleum ether and the xanthophyll going into the methanol.

TABLE 51.—*Fractionation of tocopherol between petroleum ether and methanol*

Sample	Tocopherol	Carotene	Xanthophyll	Solids [1]
	Milligrams	*Milligrams*	*Milligrams*	*Grams*
Saponified extract	208	60	45	13
Methanol soluble	108	7	39	3
Petroleum ether soluble	74	48	2	6

[1] An appreciable quantity of solids was precipitated in petroleum ether and 96-percent methanol at −5° C., and the precipitate persisted when warmed to room temperature.

Higher tocopherol concentrations have been obtained by molecular distillation. A partly saponified cottonseed oil was used as a vehicle for the plant extract. All solvent was removed, and the oily solution was distilled in a Hickman pot still. These experiments are only in a preliminary stage, but table 52 indicates what may be accomplished by this technique. The total distillation required about 8 hours, and all the carotene was destroyed. A sharper fractionation of tocopherol with little carotene destruction could undoubtedly be obtained with the improved cyclic or centrifugal molecular stills (*13*).

TABLE 52.—*Concentration of tocopherol from lima bean vine meal by molecular distillation* [1]

Fraction		Temperature	Weight	Tocopherol	
No.	Description				
		°*C.*	*Grams*	*Milligrams*	*Percent*
1	Pale-yellow oil	110–130	2. 3	2. 3	0. 1
2	do	140	9. 0	27. 9	. 3
3	do	140	2. 9	11. 9	. 4
4	Yellow semisolid	190	2. 0	107. 5	5. 4
5	Orange solid	220–230	. 8	60. 0	7. 5
6	do	245–250	1. 4	37. 5	2. 7
7	Residue (red solid)	----------	4. 0	8. 0	. 2
	Total	----------	22. 4	255. 1	--------

[1] The oil solution weighed 30 gm. and contained 9 mg. of tocopherol per gram.

Other Lipids

There are many other lipid constituents of vegetable leaf meals, including sterols, glycerides, phospholipids, and vitamin K_1. Little work has been done here with these components, but they may have value when methods for isolating them are perfected.

SUMMARY

A preliminary survey of 83 vegetable tissues occurring either as wastes or temporary surpluses showed that the leafy parts have a high content of vitamins and protein and a low content of crude fiber. A survey of the distribution, quantities, and seasonal availability of the leafy wastes incident to the production of certain of these vegetables, selected from the standpoint of nutritional value, abundance, and occurrence in large concentrations, showed that they were available in 1944 in the following estimated quantities:

	Thousand tons		*Thousand tons*		*Thousand tons*
Beets	120	Cauliflower	354	Turnips	4
Broccoli	36	Lima beans	292	Spinach	39
Cabbage	1,537	Peas	1,981		
Carrots	164	Rutabagas	4		

The plants were separated by hand into leaves, petioles, stems, pods, and other parts, and the relative proportion and chemical composition of the various parts were determined. Means were also devised for separating the relatively more valuable leaf blades from the stems by fractional drying followed either by trommeling or by air classification.

Leaves are by far the richest portion of plants in nutrient materials. Leaf meals having high carotene, riboflavin, and protein contents and a low fiber content were prepared from beet, broccoli, kale, rhubarb, rutabaga, turnip, and spinach wastes. Leaf meals rich in carotene of good nutritional value were also prepared from carrot tops and lima bean vines. It was found that rhubarb and lima bean vine meals contain large percentages of tocopherol or vitamin E. Pea vines were studied in detail, and methods of using them as feed supplements were worked out.

Protein in leaf meals ranges from 13 percent in lima bean vines to 43 percent in broccoli; carotene from 19 μg per gram in pea vines to 810 in broccoli; riboflavin from 9 μg per gram in lima bean vines to 30 in broccoli; tocopherol from 300 μg per gram in turnip tops to 1,240 in rhubarb; and crude fiber from 6.5 percent in kale to 18 percent in pea vines.

All vegetable leaf meals contain a large number of chemically and physiologically diverse compounds with one property in common—they are soluble in such materials as acetone, benzene, chloroform, ether, and petroleum ether and insoluble in water or aqueous solvents. (The ether extracts of the leaf meals under discussion amount to 2.5 to 9 percent of the total dry weight.) They include the chlorophylls, phospholipids, true fats, carotenes, xanthophylls, tocopherols or vitamin E, vitamin K_1, sterols, and hydrocarbons. Continued research may discover new and further uses for some of these substances.

The method developed at this Laboratory for drying leafy vegetable wastes is based on the principle of "fractional" drying. By subjecting the fresh material to a high-velocity stream of air at high temperature, the tender leaf portions are quickly dried and embrittled, while the more resistant stem portions remain wet and tough. The embrittled leaves are readily separated from the moist stems by simple mechanical methods. The process not only separates the more valuable portions of the waste from the less valuable part but has the additional advantage of requiring less heat for evaporation. This process has been satisfactory for all the wastes studied except pea vines, for which some modification is required.

The engineering factors involved in drying vegetable wastes on a large scale are discussed, and a proposed commercial technique for producing a high-quality leaf meal is described. The required factory equipment is specified. Typical yields and analyses of the leaf meals are given, and their processing costs are estimated. The data were obtained on a pilot-plant scale in which thousands of pounds of raw material were processed.

To determine the value of the nutrients contained in leaf meals, actual feeding experiments were necessary, as chemical analyses alone do not indicate the nutritional value of feed. Since the Laboratory did not have facilities for feeding experiments, the Delaware Agricultural Experiment Station undertook that phase of the study. The Laboratory supplied the leaf meals; the Delaware Station supplied the facilities, the birds, and the other feed ingredients required for the experiments.

Meals prepared from various leaf wastes are valuable adjuncts to poultry feed. When fed at a level of 8 percent, broccoli and turnip leaf meals were superior to alfalfa meal on the basis of feed efficiency and shank color, and lima bean vine and carrot leaf meals were equal to the alfalfa meal. On the basis of weight at 14 weeks, broccoli and carrot leaf meals were superior to alfalfa meal, and lima bean vine and turnip leaf meals were equal to it. On all three counts, pea vine meal was somewhat inferior. From 1.5 to 6 percent of broccoli leaf meal in the diet was optimum; even 1 percent was adequate if supplemented with riboflavin, either crystalline or from distiller's solubles, and was superior to 5 percent of alfalfa meal. Kale leaf meal at a level of 1.5 percent was equal to broccoli leaf meal at 1 percent supplemented with riboflavin.

Chickens found most of the leaf meals much more palatable than alfalfa meal. None of the meals showed toxicity, not even spinach, rhubarb, and beet, all of which contain considerable oxalic acid.

From the chemical analyses and the results of the feeding tests, it would seem that these leaf meals have a value proportional to their vitamin content, or at least to their carotene content.

LITERATURE CITED

(1) Anonymous.
1943. FROZEN FOODS DIRECTORY. Food Indus. 15 (11): 79–98, illus.

(2) Conner, R. T., and Straub, G. J.
1941. THE THIAMIN AND RIBOFLAVIN CONTENTS OF WHEAT AND CORN. Cereal Chem. 18: 671–677.

(3) DeFelice, D., and Fellers, C. R.
1938. CAROTENE CONTENT OF FRESH, FROZEN, CANNED, AND DEHYDRATED SPINACH. Amer. Soc. Hort. Sci. Proc. 35: 728–733.

(4) EMMERIE, A., and ENGEL, CHR.
1938. COLORIMETRIC DETERMINATION OF α-TOCOPHEROL (VITAMIN E). Rec. des Trav. Chim. des Pays-Bas 57: 1351–1355.

(5) FELLERS, C. R., ESSELEN, W. B., and FITZGERALD, G. A.
1940. THE VITAMIN B_1 AND VITAMIN B_2 (G) CONTENT OF VEGETABLES AS INFLUENCED BY QUICK-FREEZING AND CANNING. Food Res. 5: 495–502.

(6) FITZGERALD, G. A., and FELLERS, C. R.
1938. CAROTENE AND ASCORBIC ACID CONTENT OF FRESH MARKET AND COMMERCIALLY FROZEN FRUITS AND VEGETABLES. Food Res. 3: 109–120.

(7) FIXSEN, MARGARET A. BOAS, and ROSCOE, MARGARET H.
1940. TABLES OF VITAMIN CONTENTS OF HUMAN AND ANIMAL FOODS. II. Nut. Abs. and Rev. 9: 795–861.

(8) FRAPS, G. S., MEINKE, W. W., and KEMMERER, A. R.
1941. DETERMINATION OF PURE CAROTENE IN GREEN VEGETABLES AND GREEN FEEDS. Assoc. Off. Agr. Chem. Jour. 24: 739–744.

(9) FÜRTER, M., and MEYER, R. E.
1939. EINE QUANTITATIVE PHOTOMETRISCHE BESTIMMUNG VON VITAMIN E. Helvetica Chim. Acta 22: 240–250, illus.

(10) GRAVES, H. C. H.
1942. THE VITAMIN-A VALUE OF CAROTENE IN VEGETABLES. Chem. and Indus. 1942: 8–10.

(11) GRUSKIN, BENJAMIN.
1940. CHLOROPHYLL; ITS THERAPEUTIC PLACE IN ACUTE AND SUPPURATIVE DISEASE. Amer. Jour. Surg. 49: 49–55.

(12) GUGGENHEIM, K.
1944. BIOLOGICAL VALUE OF CAROTENE FROM VARIOUS SOURCES AND THE EFFECT OF VITAMIN E ON THE UTILIZATION OF CAROTENE AND OF VITAMIN A. Biochem. Jour. 38: 260–264.

(13) HICKMAN, K. C. D.
1944. HIGH-VACUUM SHORT-PATH DISTILLATION—A REVIEW. Chem. Rev. 34: 51–106, illus.

(14) HODSON, A. Z.
1940. RIBOFLAVIN CONTENT OF SOME COMMON VEGETABLES AND FRUITS. Food Res. 5: 395–398.

(15) HOFFMANN, EDMUND, TOMHAVE, A. E., KELLEY, EDWARD G., and WALL, MONROE E.
1945. BROCCOLI LEAF MEAL FOR ALFALFA MEAL IN BROILER RATIONS. Feedstuffs 17 (8): 25, illus.

(16) HOLMES, HARRY N., and LEICESTER, HENRY M.
1932. THE ISOLATION OF CAROTENE. Amer. Chem. Soc. Jour. 54: 716–720.

(17) JACOBS, MORRIS B.
1944. THE CHEMISTRY AND TECHNOLOGY OF FOOD AND FOOD PRODUCTS. vol. I, 952 pp. New York.

(18) KARRER, P., and KELLER, H.
1938. QUANTITATIVE BESTIMMUNG DER TOCOPHEROLE IN VERSCHIEDEMEN AUSGANGSMATERIALIEN. Helvetica Chim. Acta 21: 1161–1169.

(19) ——— and MORF, R.
1931. PFLANZENFARBSTOFFE XXXV. ZUR KONSTITUTION DES β-CAROTINS AND β-DIHYDRO-CAROTINS. Helvetica Chim. Acta 14: 1033–1036.

(20) KUHN, R., and BROCKMANN, H.
1932. DETERMINATION OF CAROTENOIDS. Ztschr. f. physiol. Chem. 206: 41–64.

(21) MACGILLIVRAY, JOHN H., HANNA, G. C., and MINGES, P. A.
1942. VITAMIN, PROTEIN, CALCIUM, IRON, AND CALORIE YIELD OF VEGETABLES PER ACRE AND PER ACRE MAN-HOUR. Amer. Soc. Hort. Sci. Proc. 41: 293–297.

(22) MATTILL, H. A.
1945. ANTIOXIDANTS AND SYNERGISTS. Oil and Soap 22: 1–3.

(23) MOORE, THOMAS.
1929. A NOTE ON CAROTIN AND VITAMIN A. Lancet I: 499–500.

(24) MORGAL, P. W., PETERING, H. G., and MILLER, E. J.
1941. ISOLATION OF UNSAPONIFIABLE CONSTITUENTS FROM GREEN PLANT TISSUE. Indus. and Engin. Chem. 33: 1298–1302, illus.

(25) MORRISON, F. B.
1936. FEEDS AND FEEDING. Ed. 20. 1050 pp., illus. Ithaca, N. Y.

(26) MUNSELL, HAZEL E.
1942. RIBOFLAVIN CONTENT OF SOME COMMON FOODS. Food Res. 7: 85–95.

(27) NATIONAL CANNERS ASSOCIATION
1943. CANNERS DIRECTORY. 164 pp., illus. Washington, D. C.

(28) NELSON, E. K., and MOTTERN, H. H.
1931. THE ORGANIC ACIDS OF SPINACH, BROCCOLI, AND LETTUCE. Amer. Chem. Soc. Jour. 53: 1909–1912.

(29) PETERING, H. G., MORGAL, P. W., and MILLER, E. J.
1941. LIPIDES ISOLATED FROM ALFALFA-LEAF MEAL. Indus. and Engin. Chem. 33: 1428–1432, illus.

(30) ——— WOLMAN, W., and HIBBARD, R. P.
1940. DETERMINATION OF CHLOROPHYLL AND CAROTENE IN PLANT TISSUE. Indus. and Engin. Chem., Analyt. Ed. 12: 148–151, illus.

(31) PUCHER, GEORGE W., VICKERY, HUBERT BRADFORD, and WAKEMAN, ALFRED J.
1934. DETERMINATION OF THE ACIDS OF PLANT TISSUE. II. TOTAL ORGANIC ACIDS OF TOBACCO LEAF. Indus. and Engin. Chem., Analyt. Ed. 6: 140–143.

(32) PYKE, MAGNUS.
1942. THE VITAMIN CONTENT OF VEGETABLES. Soc. Chem. Ind. Jour. 61: 149–151.

(33) REMINGTON, ROE E., and SMITH, CECIL L.
1945. SPINACH AND BONE FORMATION. Science 101: 271.

(34) RYDER, ALICE E.
1930. THE OXALIC ACID CONTENT OF VEGETABLES USED AS GREENS. Home Econ. Jour. 22: 309–314.

(35) SCHERTZ, FRANK MILTON.
1938. ISOLATION OF CHLOROPHYLL, CAROTENE, AND XANTHOPHYLL BY IMPROVED METHODS. Indus. and Engin. Chem. 30: 1073–1075, illus.

(36) SCUDI, JOHN V., and BUHS, RUDOLF P.
1941. A COLORIMETRIC OXIDATION-REDUCTION METHOD FOR THE DETERMINATION OF THE K VITAMINS. Jour. Biol. Chem. 141: 451–464, illus.

(37) ——— and BUHS, RUDOLF P.
1942. DETERMINATION OF THE TOCOPHEROLS AND THE TOCOPHERYLQUINONES BY THE COLORIMETRIC OXIDATION-REDUCTION METHOD. Jour. Biol. Chem. 146: 1–6.

(38) SEABER, W. M.
1940. THE COMMERCIAL DETERMINATION OF CAROTENE AND ALLIED PIGMENTS, WITH ESPECIAL REFERENCE TO DRIED GRASS AND OTHER LEAFY MATERIALS. Analyst. 65: 266–281.

(39) SMITH, LAWRENCE W., and LIVINGSTON, ALFRED E.
1943. CHLOROPHYLL; AN EXPERIMENTAL STUDY OF ITS WATER SOLUBLE DERIVATIVES IN WOUND HEALING. Amer. Jour. Surg. 62: 358–369.

(40) THOMPSON, HOMER C.
1939. VEGETABLE CROPS. 578 pp., illus. New York.

(41) TOMHAVE A. E., HOFFMANN, EDMUND, KELLEY, EDWARD G., WALL, MONROE E., and COLKER, DAVID A.
1944. A PRELIMINARY INVESTIGATION ON THE USE OF CERTAIN DRIED VEGETABLE WASTES AS POULTRY FEEDS. Delaware Agri. Expt. Sta. Bull. 247, 32 pp., illus.

(42) UNITED STATES BUREAU OF THE CENSUS.
1942. UNITED STATES CENSUS OF AGRICULTURE, 1940. U. S. Bur. of the Census, v. 1, 784 pp., illus.

(43) WALL, MONROE E., and KELLEY, EDWARD G.
1943. DETERMINATION OF PURE CAROTENE IN PLANT TISSUE; A RAPID CHROMATOGRAPHIC METHOD. Indus. and Engin. Chem., Analyt. Ed. 15: 18–20.

(44) ——— and KELLEY, E. G.
1946. CAROTENE LOSS IN STORED LEAF MEALS AND EXTRACTS. Indus. and Engin. Chem. 38: 215–218, illus.

(45) ——— and KELLEY, E. G.
1946. DETERMINATION OF TOCOPHEROL IN PLANT TISSUE. Indus. and Engin. Chem., Analyt. Ed. 18: 198–201, illus.

(46) ——— KELLEY, EDWARD G., and WILLAMAN, J. J.
1944. CAROTENE CONCENTRATES FROM VEGETABLE LEAF WASTES. Indus. and Engin. Chem. 36: 1057–1061, illus.

(47) WEIGAND, E. H.
1944. TURN YOUR PEA VINE WASTE INTO PROFIT. Food Packer 25 (2): 46–47.

(48) WHITACRE, JESSIE, FRAPS, G. S., YARNELL, S. H., and OBERG, A. G.
1944. EATING QUALITY AND SOME ASPECTS OF COMPOSITION OF TURNIP GREENS AT SUCCESSIVE STAGES OF GROWTH. Food Res. 9: 42–55.

(49) WILLSTÄTTER, RICHARD, and STOLL, ARTHUR.
1928. INVESTIGATIONS ON CHLOROPHYLL. Trans. by Frank Milton Schertz and Albert R. Merz. 385 pp., illus. Lancaster, Pa.

(50) WINTON, ANDREW L., and WINTON, KATE BARBER.
1935. STRUCTURE AND COMPOSITION OF FOODS. V. 2. VEGETABLES, LEGUMES, FRUITS. 904 pp., illus. New York.

(51) ZSCHEILE, F. P., BEADLE, B. W., and KRAYBILL, H. R.
1943. CAROTENE CONTENT OF FRESH AND FROZEN GREEN VEGETABLES. Food Res. 8: 299–313.