TB 462 (1935) USDA TECHNICAL BULLETINS UPDATA
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NATIONAL BUREAU OF STANDARDS 1963 A

Technical Bulletin No. 462 February 1935

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

COMPOSITION OF THE DEVELOPING ASPARAGUS SHOOT IN RELATION TO ITS USE AS A FOOD PRODUCT AND AS MATERIAL FOR CANNING

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INTRODUCTION

Asparagus (*Asparagus officinalis* L.) is a plant native to the Old World, and its young shoots have been used as food since ancient times. In temperate climates its production is confined to a few weeks in the spring. In order to extend the period of its use, various methods of preservation, including canning, drying, and holding in storage at low temperatures, have been employed. In order that these methods of preservation may be most effectively applied, it is necessary to have adequate understanding of the physical and chemical characteristics of the developing shoots and of the physiological behavior of the plant both before and after the harvest season. Within recent years a considerable amount of work directed toward this end has been carried out.

REVIEW OF LITERATURE

The table quality and market value of asparagus are influenced by a large number of factors, which include cultural practices, fertilizer treatment, the nature of the soil, seasonal conditions, the stage of development at harvesting, and the methods of handling and storage employed after harvesting. Cultural practices, methods of harvesting, and marketing have been rather fully discussed by Jones and Robbins (*7*).[1] Thompson (*13*), and others (*14,15,17*). Determinations of proximate composition and food value made by various autho have been compiled by Chatfield and Adams (*4*). These writers give the average composition as moisture 93.0 percent, protein 2.2 percent, fat 0.2 percent, ash 0.67 percent, fiber 0.7 percent, and sugar 1.34 percent, with a calorific value of 26.2 calories per 100 g of fresh material. Morse (*8, 9, 10*) has studied the composition of the shoots at different stages of maturity, the effect of fertilizer treatment upon composition, and the differences in composition of successive cuttings during the season. He shows that sugars increase during the harvest season while nitrogen and lignin decrease. The old shoots are higher in dry matter and fiber but lower in protein and fat than the young shoots.

Bisson, Jones, and Robbins (*2*) have studied some of the factors influencing the quality of the fresh material after it is harvested. They found that as the shoots increase in length crude fiber increases and sugars decrease, all the changes occurring more rapidly at higher temperatures.

Many other writers (*3, 5, 16, 17*) have reported upon one phase or another of the production or utilization of asparagus, but it seems unnecessary to review this literature, most of which has been cited by Working (*17*). One fact apparent from the analytical data reported by the various workers is that there are considerable variations in the composition of asparagus, attributable in part to differences in cultural treatment, seasonal conditions, and other uncontrolled factors, but also in part to differences in the age of the young shoots at the time of sampling and in the amounts of the basal portion included in the samples. No extensive study of the differences in chemical composition along the length of the shoot seems to have been made.

PURPOSE OF THE WORK

Since it is the young growing shoots that are used as food, and since the shoots may be harvested after they have grown for varying periods of time, it seems important to know the composition of the different portions of the length of the shoot at various stages of its growth. In preparing the material for table use or for canning, the basal portions of the shoots are cut away, and little is known as to the composition and potential food value of this material. It would also be advantageous to know the extent of the changes in chemical composition and in quality of the product as the season advances. The main purpose of this work was to secure information in regard to differences in composition and palatability of the material at different points along the growing shoot. A secondary purpose was to study the changes that occur in the composition and table quality of the young shoots as the harvesting season advances. As an aid to the understanding of the changes occurring in the growing shoots, studies were also made of the changes in composition of the roots during the cutting season. In order to determine the relationships of composition of the shoots to their suitability for table use and canning, cooking and canning tests were made upon the young shoots at short inter-

[1] Italic numbers in parentheses refer to Literature Cited, p. 23.

vals throughout the cutting season. Shoots of varying heights were also collected and divided into a series of segments from base to tip, and cooking and canning tests and chemical analyses were made upon the separate segments.

METHODS OF SAMPLING AND ANALYSIS

The material employed in the study was grown at the Arlington Experiment Farm of the United States Department of Agriculture, at Rosslyn, Va., near Washington, D.C., during the season of 1928. The bed from which the samples were taken had been planted in 1919, so that it was 8 years old at the time the work was done. The soil is a deep sandy loam, and the plants were vigorous and healthy.

The samples for the chemical analyses were uniformly collected between 9 and 10 a.m., after dew, if present, had been evaporated. This early sampling permitted completion during the day of the work necessary in the preservation of the samples for analysis and in making the cooking and canning tests upon other portions of the material.

The sampling period extended from April 20 to June 14. During this time six sets of samples of young shoots were taken. For each set, 20 to 30 shoots were selected for uniformity of size and height in the field. Each was cut at a point slightly more than 1 inch below the surface of the soil and 3 to 4 inches above the crown. In the laboratory the bases of the shoots were cut off squarely at a point 1 inch below the surface of the soil. The shoots were then cut into segments, depending in number and length upon the length of the lot of shoots. In the first set of samples the shoots were 4 inches long and were divided into four 1-inch segments; the second set was of shoots 8 inches long, which were divided into eight 1-inch segments; the shoots of the third set were 18 inches long and were divided into nine 2-inch segments; those of the fourth set were 36 inches long and were divided into nine 4-inch segments; the fifth and sixth sets were of shoots 72 inches in height, which were divided into nine 8-inch segments. At intervals of about 10 days throughout the cutting season, samples of entire young shoots 4 inches long were taken, and samples of roots were taken at the beginning, middle, and end of the season.

In preparing the samples for analysis, the lot of segments or of entire shoots was finely ground, duplicate 100-g samples were weighed out, 95-percent alcohol in quantity sufficient to give a final concentration of 75 to 80 percent was added, the material was heated to boiling, and the container was sealed and stored until the analyses were begun.

The nitrogen determinations were made upon separate samples which were rapidly dried in a current of warm air.

The extraction of the material preserved in alcohol was completed with fresh 95-percent alcohol in Soxhlet extractors; the extracts were combined and made up to volume, and aliquot portions were taken for determination of soluble solids, sugars, acidity, total astringency, and amino acid content. The residue after extraction was weighed, and duplicate portions were taken for the determination of acid-hydrolyzable polysaccharides.

Sugars were determined by the volumetric permanganate modification of the Munson-Walker method as given in the official methods of the Association of Official Agricultural Chemists (*1*).

Total nitrogen was determined by the Gunning-Arnold method as modified to include nitrates.

Acid-hydrolyzable polysaccharides were determined by hydrolysis with hydrochloric acid as prescribed in the official methods.

Total astringency was determined by titration with N/20 potassium permanganate against indigo-carmine as indicator.

Titratable acidity was determined by titration with N/10 sodium hydroxide against phenolphthalein as indicator.

Nitrate nitrogen was determined by the ferrous-chloride method for meats as described in the official methods.

Amino acids were determined in the alcoholic extract by the Van Slyke method. Since losses of amino acids may occur in material preserved in alcohol, the results can be considered as comparative only.

ANALYTICAL RESULTS

The results of the analyses upon the series of samples of shoots of various lengths after division into segments are shown in table 1.

TABLE 1.—*Composition [1] of various regions in the asparagus shoot at several stages of development*

Series and date of sampling	Length of shoot	Length of segment	Height of segment from base	Soluble solids	Insoluble solids	Total solids	Reducing sugars	Nonreducing sugars	Total sugars	Acid-hydrolyzable polysaccharides	Titratable acidity calculated as citric acid	Total astringency	Nitrate nitrogen	Amino nitrogen	Total nitrogen
	Inches	*Inches*	*Inches*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1, May 4	4	1	1	5.72	2.77	8.49	3.05	1.05	4.10	0.69	0.227	0.076	0.00	0.031	0.31
	4	1	2	5.46	3.38	8.84	2.81	1.17	3.98	.76	.241	.072	.00	.029	.42
	4	1	3	5.36	5.23	10.59	2.16	1.14	3.30	.98	.255	.100	.00	.014	.64
	4	1	4	5.06	8.15	13.21	1.07	.67	1.74	1.23	.290	.161	.00	.032	1.04
2, May 4	8	1	1	5.74	4.15	9.89	3.08	1.08	4.16	1.25	.163	.070	.00	.018	.30
	8	1	2	5.40	3.65	9.05	2.98	.94	3.92	.95	-----	.074	.00	.010	.31
	8	1	3	5.16	3.57	8.73	2.94	.86	3.80	.91	.185	.084	.00	.017	.40
	8	1	4	4.92	3.46	8.38	2.60	.92	3.52	.80	.185	.084	.00	.026	.39
	8	1	5	4.94	4.05	8.99	2.48	.64	3.12	.86	.227	.104	.00	.022	.48
	8	1	6	4.94	4.69	9.63	2.10	.80	2.90	.93	.234	.127	.00	.024	.57
	8	1	7	4.92	6.27	11.19	1.57	.85	2.42	1.00	.286	.151	.00	.025	.77
	8	1	8	4.58	8.54	13.12	.05	.24	.29	.97	.306	.239	.00	.024	1.09
3, May 12	18	2	2	6.56	6.20	12.76	3.63	1.31	4.94	1.75	.202	.081	.00	.016	.28
	18	2	4	5.98	4.82	10.80	3.39	1.29	4.68	1.30	.189	.082	.00	.013	.29
	18	2	6	5.40	3.84	9.24	3.06	1.04	4.10	1.03	.189	.085	.00	.010	.31
	18	2	8	4.94	3.32	8.26	2.87	.69	3.56	.85	.174	.081	.00	.014	.30
	18	2	10	4.62	2.94	7.56	2.68	.66	3.34	.66	.189	.098	.00	.021	.36
	18	2	12	4.56	3.39	7.95	2.43	.73	3.16	.75	.228	.096	.00	.021	.44
	18	2	14	4.54	4.30	8.84	2.11	.75	2.86	.82	.270	.100	.00	.031	.57
	18	2	16	4.60	5.68	10.28	1.58	.66	2.24	.86	.274	.144	.00	.029	.87
	18	2	18	4.48	8.42	12.90	.10	.20	.30	.80	.300	.217	.00	.027	1.13
4, May 21	36	4	4	6.04	7.42	13.46	3.36	1.38	4.74	2.00	.207	.049	.0030	.030	.24
	36	4	8	5.28	6.21	11.49	3.02	1.30	4.32	1.78	.215	.048	.00	.023	.24
	36	4	12	4.90	5.15	10.05	2.89	1.09	3.98	1.44	.217	.058	.00	.020	.26
	36	4	16	4.70	4.42	9.12	2.78	.78	3.56	1.22	.220	.052	.00	.038	.25
	36	4	20	4.50	3.96	8.46	2.60	.78	3.38	.91	.228	.059	.00	.032	.28
	36	4	24	4.40	3.72	8.12	2.40	.80	3.20	.99	.227	.053	.00	.024	.30
	36	4	28	4.32	3.94	8.26	2.08	.60	2.68	.87	.309	.069	.00	.024	.33
	36	4	32	4.26	4.76	9.02	1.41	.64	2.05	.95	.345	.121	.00	.020	.45
	36	4	36	4.22	6.48	10.70	.23	.29	.52	.76	.361	.203	.00	.027	.78

[1] Expressed as percentage of fresh, green weight

TABLE 1.—*Composition of various regions in the asparagus shoot at several stages of development*—Continued

Series and date of sampling	Length of shoot	Length of segment	Height of segment from base	Soluble solids	Insoluble solids	Total solids	Reducing sugars	Nonreducing sugars	Total sugars	Acid-hydrolyzable polysaccharides	Titratable acidity calculated as citric acid	Total astringency	Nitrate nitrogen	Amino nitrogen	Total nitrogen
	Inches	*Inches*	*Inches*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
5, June 1	72	8	8	6.10	17.35	23.45	2.93	1.35	4.28	4.65	0.338	0.104	0.0040	0.031	0.30
	72	8	16	5.80	16.54	22.34	2.68	1.20	3.88	4.17	.342	.141	.0031	.038	.29
	72	8	24	5.64	15.36	21.00	2.67	.95	3.62	3.52	.377	.116	.0032	.040	.34
	72	8	32	5.64	15.44	21.08	2.34	1.02	3.36	3.54	.393	.128	.0031	.054	.38
	72	8	40	5.38	16.39	21.77	2.35	.73	3.08	3.65	.404	.134	.0048	.052	.45
	72	8	48	5.12	18.12	23.24	2.34	.72	3.06	3.99	.443	.128	.0031	.053	.58
	72	8	56	5.20	19.49	24.69	1.95	.77	2.72	4.25	.455	.145	.0033	.061	.65
	72	8	64	5.04	20.39	25.43	1.64	.80	2.44	4.61	.500	.172	.0029	.064	1.02
	72	8	72	5.64	15.08	20.72	1.05	.29	1.34	2.64	.491	.486	.0006	.074	1.14
6, June 11	72	8	8	5.80	16.99	22.79	2.78	.80	3.58	3.99	.264	.129	.0080	.026	.34
	72	8	16	5.96	14.75	20.71	2.78	.82	3.60	3.41	.338	.121	.0094	.028	.35
	72	8	24	5.84	15.28	21.12	2.59	1.06	3.65	3.48	.419	.131	.0094	.041	.41
	72	8	32	5.66	17.96	23.62	2.40	.90	3.30	4.09	.394	.135	.0093	.040	.45
	72	8	40	5.64	18.18	23.82	2.35	.95	3.30	3.93	.455	.150	.0098	.028	.46
	72	8	48	5.08	20.88	25.96	2.09	.53	2.62	4.57	.409	.172	.0110	.029	.52
	72	8	56	5.04	23.36	28.40	2.08	.24	2.32	4.70	.351	.208	.0119	.044	.59
	72	8	64	5.20	22.22	27.42	1.68	.34	2.02	4.78	.442	.264	.0149	.039	.59
	72	8	72	5.48	21.77	27.25	1.65	.49	2.14	4.62	.449	.276	.0155	.040	.60

TOTAL SOLIDS

The percentage of total solids present in the young shoots varies continuously in amount from segment to segment throughout their entire length. In figure 1 the percentage of total solids per segment in shoots of various lengths has been plotted against the height of the segment from the base. In shoots 4 inches long the total solids are highest in the terminal inch and decrease progressively toward the base. In shoots 8 inches long total solids are likewise highest in the terminal inch and decrease progressively to a point 4 inches above the base, from which point they increase progressively toward the base, with the result that total solids are lowest in the middle portion of the shoot. In the 18-inch shoots total solids are lowest at a point 10 inches above the base and increase progressively both upward and downward. In the 36-inch shoots total solids are highest in the basal segments,

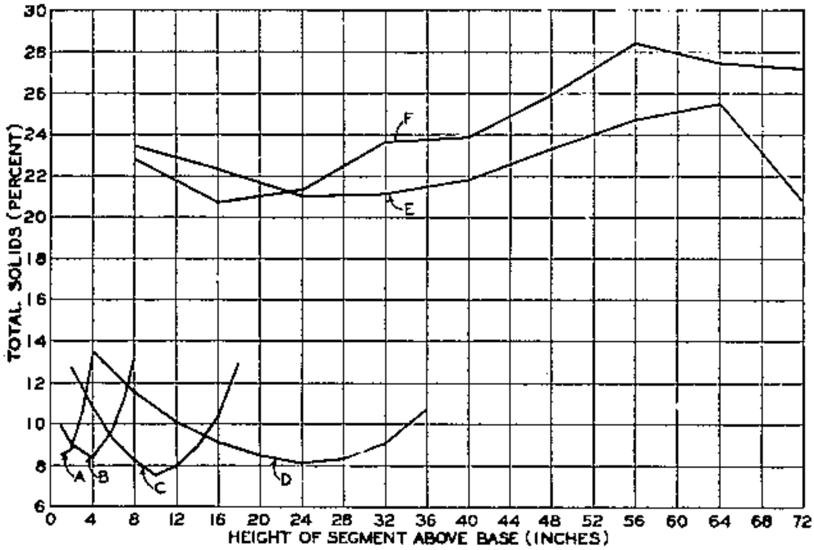

FIGURE 1.—Percentage of total solids in segments of developing asparagus stalks at different heights above the base: *A*, Stalks 4 inches tall; *B*, stalks 8 inches tall; *C*, stalks 18 inches tall; *D*, stalks 36 inches tall; *E* and *F*, stalks 72 inches tall.

decrease progressively for 24 inches, then rise again toward the tip, but less rapidly and to a lower maximum than in 18-inch shoots, possibly because of the greater length of the terminal segments analyzed. In the 72-inch shoots the total solids show a large increase throughout as a result of increases in insoluble solids, probably largely in cellulose and lignin, due to development and thickening of the structural elements. There is still a tendency for total solids to be lowest at a point intermediate between tip and base, but this tendency is much less marked than in younger shoots, and the region of lowest solids has shifted to a region nearer the base. The total solids of the tip did not vary greatly in shoots of different lengths up to 36 inches, but total solids of the basal region increased rapidly with increasing height, reaching a high value in shoots 72 inches high. Consequently the moisture content, which is merely the inverse of total solids, varies greatly in different parts even of the edible portion of the growing shoot. These variations in moisture content have an important influence upon the quality of the food material prepared from the stalks. This will be discussed more fully in a later section.

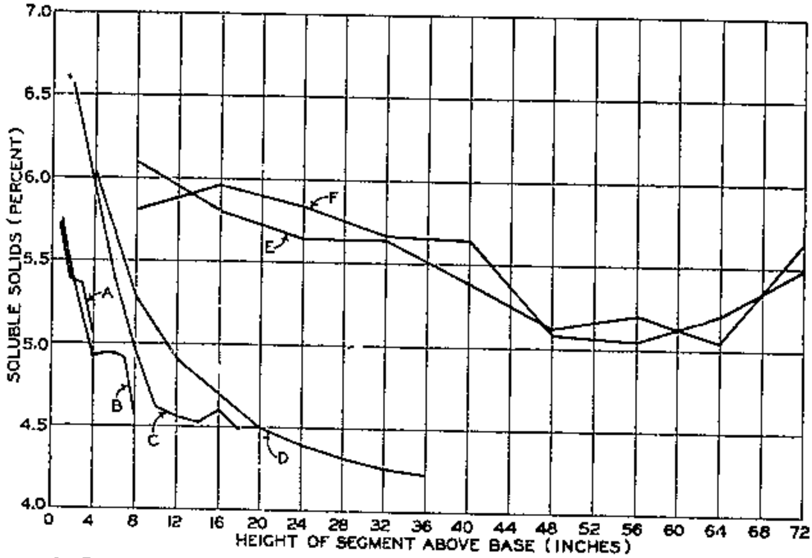

FIGURE 2.—Percentage of solids soluble in alcohol in segments of developing asparagus stalks at different heights above the base: *A*, Stalks 4 inches tall; *B*, stalks 8 inches tall; *C*, stalks 18 inches tall; *D*, stalks 36 inches tall; *E* and *F*, stalks 72 inches tall.

The alcohol-soluble and alcohol-insoluble fractions of the total solids also show rather striking variations in amount along the length

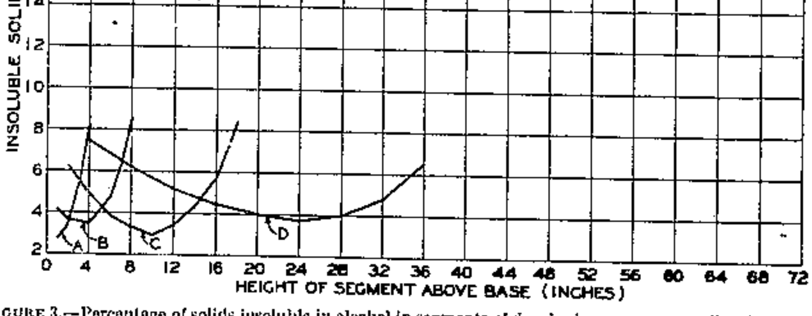

FIGURE 3.—Percentage of solids insoluble in alcohol in segments of developing asparagus stalks at different heights above the base: *A*. Stalks 4 inches tall; *B*, stalks 8 inches tall; *C*, stalks 18 inches tall; *D*, stalks 36 inches tall; *E* and *F*, stalks 72 inches tall.

of the shoot, as is shown in figures 2 and 3. The alcohol-soluble fraction of the total solids is highest in the basal segment and decreases rather regularly toward the tip in shoots up to and including

36 inches in height. In shoots 72 inches in height the alcohol-soluble solids are fairly constant in the lower half of the shoot, then decrease somewhat, rising again in amount toward the tip. The percentage of insoluble solids is highest at the tip and falls off sharply toward the base in the 4-inch and 8-inch shoots, whereas in the 18-inch shoots insoluble solids decrease from the tip to about the middle of the shoot, then increase again toward the base. In the 36-inch shoots the percentage of insoluble solids is highest at the base and decreases in successive segments to a minimum at 24 inches, then rises toward the tip. In the 72-inch shoots the insoluble solids are practically constant in amount from the base to the midregion, then rise considerably to decline again in the terminal segment. In the longer shoots insoluble solids make up the greater portion of the total solids of the tips, while

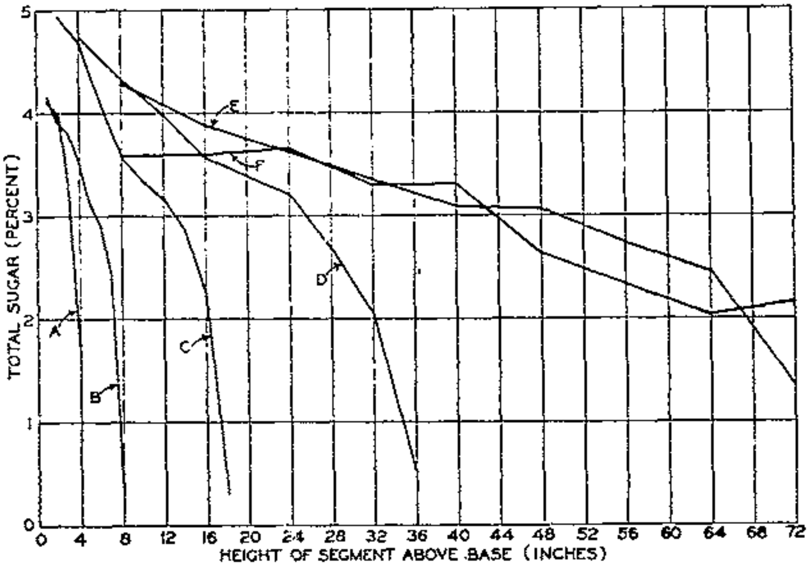

FIGURE 4.—Percentage of total sugars in segments of developing asparagus stalks at different heights above the base: *A*, Stalks 4 inches tall; *B*, stalks 8 inches tall; *C*, stalks 18 inches tall; *D*, stalks 36 inches tall; *E* and *F*, stalks 72 inches tall.

soluble solids are larger in amount than insoluble solids in the basal segments of the 4-inch and 8-inch shoots and smaller in amount in the bases of the 36-inch and 72-inch shoots.

SUGARS

The percentage of total sugars in all cases is highest in the basal segments and decreases as the growing tip is approached (fig. 4). The sugar content of the basal segment is relatively constant regardless of the height of the shoot. In shoots up to 36 inches in height the terminal segments are almost sugar-free. With practical cessation of increase in height, as in the 72-inch shoots, sugars become much more uniformly distributed throughout the length of the shoot.

Approximately two-thirds of the total sugar is in the form of reducing sugars. Both reducing and nonreducing sugars are highest in amount in the basal segments and decrease rather regularly toward the tip in shoots of all lengths. The concentration gradient of sugars along the shoot is that which would be expected if the sugars were being transported from the roots to the growing tip. It may be noted that sugars make up more than 50 percent of the soluble solids in the basal segments and that the proportion of sugars present in the soluble solids decreases fairly regularly from base to tip.

ACID-HYDROLYZABLE POLYSACCHARIDES

The percentage of acid-hydrolyzable polysaccharides is relatively low in all regions of the shoot at all stages of development. In shoots up to 36 inches in height the percentage is highest in the basal segments and practically constant in amount in the upper half of the shoot; in 72-inch shoots, which had practically ceased to elongate, there is a large increase in content of acid-hydrolyzable polysaccharides at all levels and especially in the upper segments, where the

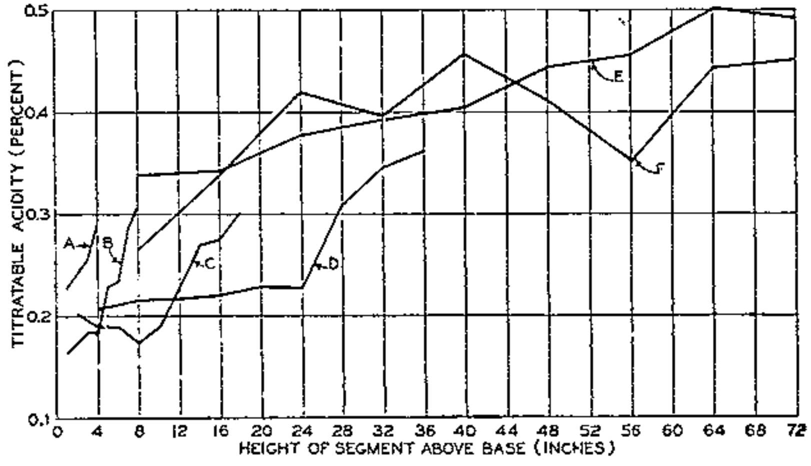

FIGURE 5.—Percentage of titratable acidity in segments of developing asparagus stalks at different heights above the base: *A*, Stalks 4 inches tall; *B*, stalks 8 inches tall; *C*, stalks 18 inches tall; *D*, stalks 30 inches tall; *E* and *F*, stalks 72 inches tall.

amount present equals or exceeds that found in the basal segments. According to Tanret (*12*), starch is not present in the asparagus plant, inulinlike substances occurring instead.

TITRATABLE ACIDITY

The titratable acidity of the shoots is relatively low in all parts and at all stages of development, but there is a tendency for its amount to increase with increase in height and age. In the 4-inch and 8-inch shoots acidity increases fairly regularly from base to tip; in the 18-inch and 36-inch shoots it is fairly low in the lower half and increases progressively toward the tip in the upper half; in the 72-inch stalks acidity is higher throughout, with a tendency to increase from the base toward the tip.

In figure 5 titratable acidity is plotted against the distance of the segment above the base. There are some irregularities in the curves, which are attributable, at least partially, to the difficulty of exactly determining the end point in the titration, but the picture presented is quite clear. So long as growth in length is actively continuing, the tip is a region of high metabolic activity with a relatively high content of titratable acidity; with the cessation of this growth in length and the development of chlorophyll, acidity tends to become equalized throughout the length of the shoot.

TOTAL ASTRINGENCY

The astringent substances, collectively designated for convenience as tannins, are of importance in the present connection because of their influence on the flavor of the product and their possible relation to the bitterness which is sometimes complained of in asparagus. It may be seen from the data in table 1 that the astringency or tannin content of asparagus shoots, as compared with that of many fruits and vege-

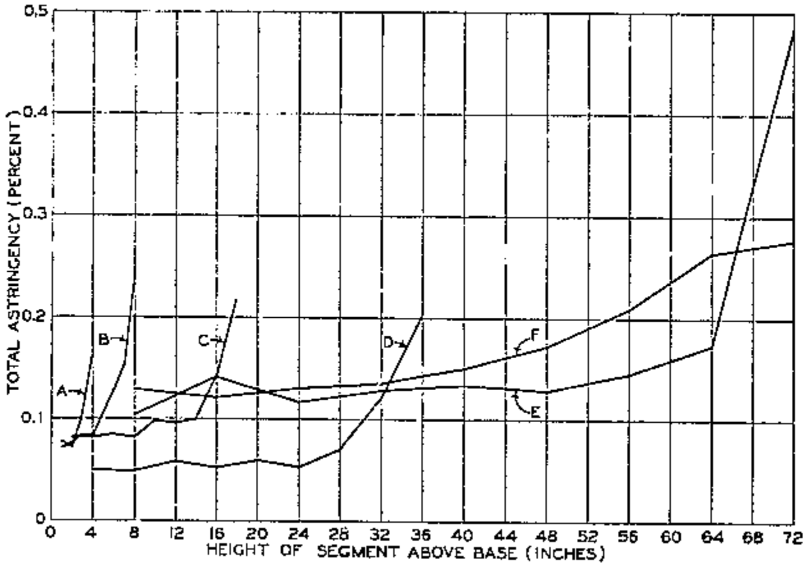

FIGURE 6.—Percentage of total astringency in segments of developing asparagus stalks at different heights above the base: *A*, Stalks 4 inches tall; *B*, stalks 8 inches tall; *C*, stalks 18 inches tall; *D*, stalks 36 inches tall; *E* and *F*, stalks 72 inches tall.

tables, is medium to low in amount. Figure 6 shows in detail the total astringency content of the various regions in shoots of various lengths. In general, the basal segments have the lowest total astringency. In young shoots the total astringency rises rapidly as the tip is approached; in older shoots total astringency remains at a comparatively low level from the base throughout most of the length, rising rather rapidly in the last one-third or one-fourth of the length to a maximum at the tip. The astringency of the shoots 36 inches in length is somewhat lower than that of either younger or older shoots; the differences are not great and may be due to chance variation in this particular set of samples. The shoots of maximum length are also maximum in their total astringency. Throughout the series of samples a high content of substances that reduce potassium permanganate in the cold is present in the apical region and segments immediately adjacent thereto, the amounts present becoming progressively less toward the basal region of the shoot.

TOTAL NITROGEN

The percentage of total nitrogen in all cases is lowest in the basal segments and does not differ greatly in this region in shoots of various heights, and the terminal segments vary but little in stalks up to 18 inches in height. It increases rather rapidly with increasing height of the segment above the base and especially in the last 3 or 4 segments. The very high concentration gradient of total nitrogen from base to tip in stalks up to and including 18 inches in height is especially worthy of note (fig. 7).

NITRATE NITROGEN

Nitrates are absent in all the young shoots, but are present in small amounts in the shoots 72 inches in length. In these the leafy structures were developed, and it appears probable that protein synthesis

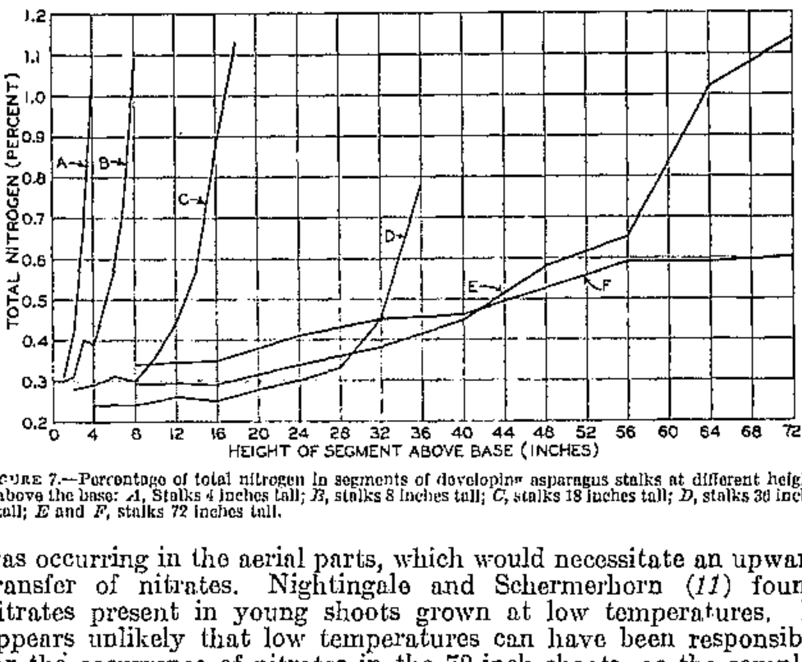

FIGURE 7.—Percentage of total nitrogen in segments of developing asparagus stalks at different heights above the base: *A*, Stalks 4 inches tall; *B*, stalks 8 inches tall; *C*, stalks 18 inches tall; *D*, stalks 36 inches tall; *E* and *F*, stalks 72 inches tall.

was occurring in the aerial parts, which would necessitate an upward transfer of nitrates. Nightingale and Schermerhorn (*11*) found nitrates present in young shoots grown at low temperatures. It appears unlikely that low temperatures can have been responsible for the occurrence of nitrates in the 72-inch shoots, as the samples were taken in June.

AMINO NITROGEN

As already pointed out, the preservation of the material in alcohol may have permitted changes in amino-nitrogen content so that the figures have only comparative value. They appear to show that amino nitrogen is fairly equally distributed throughout the length of the youngest shoots, with a tendency to become higher in amount in the upper regions of older, full-grown shoots. The figures indicate a tendency to a slow increase in amino-nitrogen content with increase in height, which becomes more pronounced in the full-grown 72-inch shoots.

CONCENTRATION GRADIENTS IN GROWING SHOOTS

Briefly summarizing the foregoing discussion, the concentration gradients found in the rapidly elongating shoots are those that would be expected in any plant organ developed at the expense of food material supplied to it at its base, transported throughout its length, and elaborated in an apical meristematic region. Alcohol-soluble solids and total sugars in the growing shoot are always maximum in the basal segment and show a progressive and rather rapid decrease toward the tip. Total solids and alcohol-insoluble solids are maximum in the terminal segment and decrease rather regularly toward the base in the growing portion of the shoot. Total nitrogen shows a rather rapidly rising concentration gradient from base to tip in the growing shoots. Titratable acidity and total astringency are maximum in the terminal segments at all stages. With the completion of growth in height and the establishment of photosynthetic activity in the old shoots, alcohol-soluble solids and total sugars increase in the upper portions of the shoot but without destroying the original gradient, whereas total solids increase greatly in all parts of the shoot but most markedly in the upper half.

CHANGES IN COMPOSITION OF YOUNG SHOOTS WITH ADVANCE OF CUTTING SEASON

For use in the study of changes in the composition of the young shoots with advance of the cutting season, a series of six samples, each of which with the exception of the first was made up of shoots 4 inches in length cut at a point 1 inch below the surface of the soil, were taken at intervals between April 20 and June 14. The shoots of the first sample were cut 1 inch below the surface of the soil but were only 2 to 3 inches in length and therefore not comparable with the others. In all cases the analytical sample consisted of duplicate 100-g portions of pulp obtained by grinding 20 to 30 shoots and thoroughly mixing the ground material before weighing out the samples. The results of the analyses are presented in table 2.

TABLE 2.—*Changes in composition of shoots and roots of asparagus as the cutting season advances*

Part of plant and date of sampling	Length	Soluble solids	Insoluble solids	Total solids	Reducing sugars	Nonreducing sugars	Total sugars
Shoot:	*Inches*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Apr. 20	3	5.68	0.87	12.55	1.74	1.07	2.81
Apr. 27	4	5.60	4.22	9.82	2.07	1.31	3.08
May 11	4	5.65	4.18	9.83	2.46	1.37	3.83
May 21	4	5.00	3.90	8.90	2.29	.69	2.98
June 1	4	4.50	4.31	8.81	1.73	.45	2.18
June 14	4	4.62	4.16	8.78	1.34	.78	2.12
Roots:							
Apr. 20		12.80	11.97	24.77	.05	10.99	11.04
May 21		12.90	9.35	22.25	.05	9.22	9.27
June 14		11.02	9.75	20.77	.08	7.92	8.00

TABLE 2.—*Changes in composition of shoots and roots of asparagus as the cutting season advances*—Continued

Part of plant and date of sampling	Length	Acid-hydrolyzable polysaccharides	Titratable acidity calculated as citric	Total astringency	Nitrate nitrogen	Amino nitrogen	Total nitrogen
	Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Shoot:							
Apr. 20	3	1.14	0.250	0.098	0.00	0.028	[illegible]
Apr. 27	4	.80	.250	.092	.00	.021	.70
May 11	4	.80	.270	.098	.00	.034	[illegible]
May 21	4	.70	.255	.081	.00	.028	.61
June 1	4	.77	.201	.113	.00	.018	.56
June 14	4	.70	.280	.090	.00	.021	.53
Roots:							
Apr. 20		2.50	.454	.247	.0021	.102	[illegible]
May 21		2.00	.358	.268	.0025	.100	.32
June 14		2.00	.300	.257	.0006	.098	[illegible]

Examination of the data shows that although the differences between successive samples are small, the differences shown by certain constituents move very consistently in one direction. Total solids, including both the soluble and the insoluble fractions, total sugars, and total nitrogen show a slight but significant tendency to decrease from April 27 onward, with the result that the final sample, taken on June 14, is very definitely lower in amounts of all these constituents than the comparable sample taken on April 27. These results are not in agreement with those of Morse (*10*), who found that sugar increased while total solids remained practically constant throughout the sampling period (May 17 to June 14). The material employed by Morse consisted of shoots 10 inches in height, "cut as close to the crown as possible", and the analytical samples were preserved by breaking into short pieces and drying in an oven at 55° to 60° C. The samples consequently contained a much larger proportion of the basal portions of the shoots than was present in the material used in the present study. When it is recalled that sugar is always maximum and total nitrogen minimum in amount at the base of the shoot, it becomes apparent that the relative amount of the basal portion included in the sample will have a marked effect upon its composition. It is suggested that the differences in methods of taking and preserving samples, together with the very considerable differences in length of day, mean temperature and rainfall between Amherst, Mass., and Washington, D.C., at the season during which the samples were taken are responsible for the differences between the results here reported and those of Morse.

CHANGES IN COMPOSITION OF ROOTS DURING CUTTING SEASON

Only three sets of samples were taken for studies of changes in composition of the roots during the cutting season, the first on April 20, the second on May 21, and the third on June 14. The analytical results (table 2) show a considerable decrease in total sugars, with less marked decreases in acid-hydrolyzable polysaccharides and in total solids, including both soluble and insoluble fractions, and progressive decreases in total nitrogen and in titratable acidity. By reason of the small number of samples and the consequent possibility of chance variation, the results cannot be considered very conclusive, but they are consistent with themselves, and the nature and direction of the changes are in essential agreement with those reported by Morse (*8*, *9*).

TESTS UPON CANNING QUALITY AND PALATABILITY

The canning tests had two general objectives, one the determination of the relation of age and height of shoot to canning quality, the other to ascertain the effect of advance of the cutting season upon canning quality of shoots at a like degree of development.

For the studies upon the relation of quality to height of shoot, a series of samples of shoots 4, 8, 18, and 36 inches in height were collected, divided into segments corresponding in length to those into which the corresponding samples for chemical analysis had been divided, and the various lots of material thus obtained were used in the canning tests. The shoots were uniformly cut at a distance of 1 inch below the soil, and were so selected as to be directly comparable with those employed in the analyses. In addition to the canning tests, numerous cooking tests were made directly upon the fresh material as taken from the field. These tests served as checks upon the results of the canning tests and afforded aid in determining the relative palatability of the various lots of material.

In shoots 4 inches in height, which were divided into 1-inch segments for canning separately, the basal segments were nearly white and the tip segments slightly green. In the 8-inch shoots, which were also divided into 1-inch segments, the tip segment and the two next below it were moderately green, the basal segment nearly white, and the intermediate segments faintly green. The 18-inch shoots were cut into 2-inch segments; the development of chlorophyll was somewhat more pronounced than in the 8-inch shoots. The 36-inch shoots were cut into 4-inch segments; the upper portions of these shoots were very bright green, and short side branches were beginning to develop in some of them. The shoots ranged between five-eighths and seven-eighths of an inch in diameter at the base, decreasing in diameter toward the tip. The diameter of the shoot continues to increase for some time after it appears aboveground, so that shoots 4 inches in height were somewhat smaller at the base than those of greater height.

Before any treatment was given the material a number of representatives from each lot were tested for resistance to pressure by means of the pressure tester described by Culpepper and Magoon (*6*) equipped with a blunt plunger 0.027 inch in diameter.

No. 2 tin cans were filled with the segments, which were then covered with 2-percent brine. The cans were exhausted in flowing steam for 2 minutes, sealed, and processed at 10 pounds steam pressure for 30 minutes. At the end of the processing period they were cooled in running water and stored for a short time before being opened for examination.

For the study of the changes in cooking and canning quality of the young shoots in the course of the cutting season, lots of young shoots 4 inches long, cut 1 inch below the surface of the soil, were collected on April 27, May 21, June 1, and June 14. The shoots were canned entire, and the canning procedure and processing time were the same as just described. In addition, less complete series of tests upon stalks of greater length than 4 inches were made from time to time throughout the season.

At the end of the storage period, which was slightly more than a month in length, the cans were opened, the color and odor of the contents compared, and determinations of resistance to pressure made. In order that these pressure tests might be directly comparable with those made upon the material prior to processing, it was necessary to devise a specially sensitive modification of the pressure tester used, so that fairly accurate readings might be obtained. After the pressure tests had been made the various lots of material were judged as to general appearance, texture, and flavor. The group of persons taking part in judging the material consisted for the most part of the writers and members of the immediate laboratory. While individual members of the group differed greatly in their preferences as to taste, there was complete agreement in regard to practically all the statements herein made.

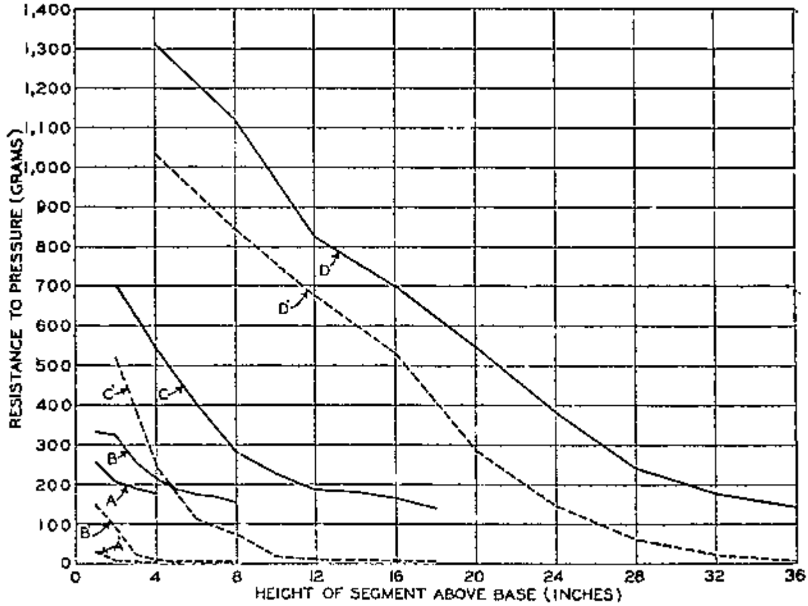

FIGURE 8.—Resistance to pressure of segments of asparagus stalks at different heights above the base, before and after canning. *A*, Stalks 4 inches tall, before canning; *A′*, after canning. *B*, Stalks 8 inches tall, before canning; *B′*, after canning. *C*, Stalks 18 inches tall, before canning; *C′*, after canning. *D*, Stalks 36 inches tall, before canning; *D′*, after canning.

QUALITY IN RELATION TO AGE AND HEIGHT OF SHOOT

The results of the examination of the canning experiment upon shoots of various heights subdivided into segments which were separately canned are summarized in table 3.

RESISTANCE TO PRESSURE

One of the most striking features of these tests was the very great reduction in resistance to pressure resulting from processing, shown by the figures of the last two columns of table 3 and represented graphically in figure 8. This decrease in resistance is apparently due to loss of turgor of the cells, to changes in the middle lamellae, and possibly to changes in the polysaccharides of the tissues. The coagulation of proteins and other heat-coagulable constituents would tend to increase the firmness of the material.

As has been briefly pointed out in an earlier section, the resistance to pressure in the fresh shoot, regardless of its length, is maximum in the basal segment and decreases continuously toward the tip. This continues to hold true after the material has been canned; resistance to pressure is highest in the basal segment, decreases rapidly in the segments just above the base, then more slowly as the tip is approached. The region of the shoot most prone to collapse and disintegration after canning was not the tip, but a region corresponding very closely in shoots of various lengths to that shown by the chemical analyses to be the region of maximum moisture content, hence lying slightly above the middle of the shoot. While the terminal segments were very tender, they did not collapse or disintegrate. A similar behavior was exhibited when the fresh material was heated as in cooking. In this connection the small size of the cells of the tip, their high content of proteins and heat-coagulable constituents such as albumins, and their high content of insoluble solids are probably significant.

TABLE 3.—*Results of canning tests upon segments of developing asparagus stalks*

Date of canning	Height of stalk	Height of segment from base	Length of segment	Color	Presence of fiber	Texture	Flavor	Pressure test before canning	Pressure test after canning
	Inches	*Inches*	*Inches*					*Grams*	*Grams*
May 21	4	0–1	1	Nearly white	Slightly noticeable	Medium coarse	Good, a little bitterness noted in some stalks.	255	30
	4	1–2	1	Pale greenish	Not noticeable	Medium fine	Pleasing	206	8
	4	2–3	1	Pale greenish brown	do	Very fine	Very pleasing	189	4
	4	3–4	1	Quite greenish brown	do	do	do	175	4
May 25	8	0–1	1	Nearly white	Very apparent	Coarse	Fair; some stalks slightly bitter	331	148
	8	1–2	1	do	Quite apparent	do	Mild	324	89
	8	2–3	1	Very slightly brownish	Somewhat apparent	do	Mild, pleasing	256	22
	8	3–4	1	Slightly brownish	Scarcely noticeable	Medium fine	Quite pleasing	214	9
	8	4–5	1	Greenish brown	Not apparent	Quite fine	Very pleasing	187	4
	8	5–6	1	do	do	Very fine	do	173	4
	8	6–7	1	do	do	do	Very rich	167	3
	8	7–8	1	do	do	do	Very rich, pleasing	153	3
May 28	18	0–2	2	Nearly white	Very fibrous	Tough	Not rich, slightly bitter	709	522
	18	2–4	2	Slightly browned	do	Medium coarse	Some stalks slightly bitter	548	249
	18	4–6	2	do	Quite fibrous	do	Mild, pleasing	403	112
	18	6–8	2	Brownish	Slightly noticeable	Medium fine	do	280	72
	18	8–10	2	Greenish brown	Not apparent	Fine	do	226	18
	18	10–12	2	do	do	Very fine	Rich, pleasing	185	8
	18	12–14	2	do	do	do	do	180	
	18	14–16	2	do	do	do	do	163	4
	18	16–18	2	do	do	do	do	138	3
June 1	36	0–4	4	Nearly white	Woody, fibrous	Hard, coarse	Some stalks slightly bitter	1,315	1,035
	36	4–8	4	Very slightly brownish	do	do	do	1,121	845
	36	8–12	4	Somewhat brownish	Very fibrous	Medium hard	Mild, pleasing	828	678
	36	12–16	4	Brownish	Quite fibrous	Somewhat coarse	do	700	530
	36	16–20	4	Greenish brown	do	Coarse	do	547	289
	36	20–24	4	do	Somewhat fibrous	do	do	381	149
	36	24–28	4	do	do	Moderately coarse	do	242	62
	36	28–32	4	do	Scarcely noticeable	Quite fine	do	178	23
	36	32–36	4	Intense greenish brown	Not noticeable	Very fine	Very rich	143	4

The basal portions of the taller shoots are extremely resistant to pressure in the fresh condition, and the resistance remains high after processing, obviously as a result of the presence of woody fibers, the pericyclic fibers, in a ring near the outer surface. The central portions of the stalks of medium height are relatively much less fibrous and consequently may be used in cooking or for canning when corresponding segments of the entire stalk are much too fibrous for use.

COLOR

In the fresh material 1 or 2 inches of the basal portions was in all cases very nearly colorless. As a result of the development of chlorophyll the shoots become progressively more green above the surface of the soil so that the tip or upper portion of the taller shoots is quite green. The color is greatly altered during processing, the chlorophyll becoming more or less decomposed, with the result that the bright green of the fresh material is changed to greenish brown. The same change occurs in cooking, although it is usually less pronounced. The tips also become darker after being cooked and then allowed to stand in the air, probably as a result of oxidation of tannins and related substances. The color of the portion of the shoot located at or below the surface of the soil changes very little during the heating usually given in canning and cooking, and the darkening occurring on exposure to the air is less pronounced than in the tips. It was evident that the color of the shoots, both before and after canning or cooking, varies continuously from base to tip at all stages of development.

FLAVOR AND PALATABILITY

The canned material and the freshly cooked product of the different lots of shoots were carefully compared with respect to the flavor and palatability of the individual segments. The different lots had a pronounced characteristic flavor which was common to all, but on the other hand there was something distinct and different in each lot and in each segment along the shoot. In the 4-inch shoots the basal segments were strongly flavored, slightly bitter, somewhat sweeter, and a little more acid than the tips. The tips were mild with a rich nutlike or meatlike flavor; the intermediate segments were intermediate in their effect upon the palate. The differences in apparent sweetness agreed with the differences in sugar content shown by the chemical analyses; the apparent acidity did not agree with the titratable acidity results, but ran more closely with the results of hydrion concentration determinations. A typical series of determinations made May 4, 1928, using the hydrogen electrode, gave the following pH values for the separate 1-inch segments of 4-inch shoots: Terminal inch, 6.76; second inch, 6.54; third inch, 6.32; basal inch, 6.37. The differences in acidity and sweetness to taste appeared to be of very minor importance.

In the 8-inch shoots the differences between extremities were very much as in the 4-inch shoots. Two or three of the basal segments of the 8-inch shoot were a little more strongly flavored than the others, and the tip was richer and distinctly more pleasing in flavor than portions nearer the base. It was apparent that the flavor and palatability of the shoot varies continuously along its entire length, both as to character and intensity. The flavor and palatability of the terminal 2 or 3 inches seemed to be of relatively constant quality in shoots of differing height, but in the case of the taller shoots the tips in some instances had a slightly denser consistency and a somewhat different and less pleasing flavor. The diameter of the tip segments was much smaller and the color was rather dark green in the case of the taller shoots, which detracted from the appearance and attractiveness of the product. The flavor of the basal portions of shoots of various heights differed considerably more than did the tips of the same shoots, but the difference was one of intensity rather than of character and quality of flavor. These differences were noted in both the canned and the freshly cooked product.

Some attention was given to the question as to how much of the shoots of various heights is suitable for use as food. It is obvious from the foregoing discussion that the terminal or tip portion is the most desirable portion of the stalk. The basal portion near the crown of the plant is hard and fibrous, as a consequence of the development of the pericyclic fibers, a ring of fibers just beneath the cortex. The central portion of the stalk for 3 or 4 inches above the soil surface is relatively free from fibers until the stalks have grown to a considerable height, and hence can be made suitable for use by peeling or stripping. In shoots that were just emerging from the soil, about 5 inches in total height, the portion too hard for use as food was about 2½ inches in length. The proportion of edible material to hard fibrous portion varies very considerably during the development of the shoot. It was found in the canning experiments and cooking tests upon fresh material that shoots 4 inches in length, cut 1 inch below the soil surface, made an agreeable food product throughout their entire length, although fibers were beginning to develop in the outer ring for a distance of one-half to 1 inch at the base. In stalks 8 inches long 1 to 2 inches of the basal portion was distinctly too tough and fibrous to be highly palatable, and in an additional 1 or 2 inches of length the fibers were noticeable but not sufficiently abundant to make the material unsuitable for use. Four and one-half to 5 inches of the upper part of the 8-inch shoots was of the highest table quality. The central portion was palatable throughout its entire length after the fibers were stripped off. In shoots 18 inches in height 6 to 8 inches of the basal portion was sufficiently hard to be distinctly objectionable, and fibers were noticeable in an additional inch or two, leaving approximately 8 inches of the tip portion that was of highest table quality. When stripped, the central portion, even at the base, was still quite palatable. In shoots 36 inches in height the basal segments were hard and woody, the fibrous character decreasing with height so that some 8 or 10 inches of the tip was satisfactory for table use insofar as palatability and flavor were concerned. The canned product was much less attractive by reason of the smaller size of the shoots, the presence of occasional short side branches, and the development of deep green color. The foregoing discussion applies to material taken near the middle of the cutting season.

It also appears from these studies that there is a larger amount of edible material present per stalk when the stalks are 18 inches tall than at any other height here examined. There are very decided differences between individual stalks, and the results vary considerably at different times during the cutting season, but this was the case for the stalk during the middle of this particular cutting season.

QUALITY IN RELATION TO TIME OF CUTTING

As previously stated, the material employed in the study of quality of product in relation to time of cutting consisted of four cuttings, each made up of shoots 4 inches in length and cut 1 inch below the soil surface, taken on April 27, May 21, June 1, and June 14, which were canned without subdivision.

The differences in quality between the four lots were very slight; all the material was of good table quality, and it appears evident that the quality of shoots at this early stage of development is very similar throughout the entire cutting season. This may have been due in part to the fact that the shoots used were rather carefully selected for uniformity of size, which became somewhat more difficult as the season advanced.

A complete series of cooking and canning tests upon shoots more than 4 inches in height taken at intervals throughout the season was not made, but a sufficient number of such tests were made to make it evident that differences between the early-season shoots and the later ones appear as the shoots become taller. In stalks of equal height, the basal portion is more fibrous in stalks developing late in the season. Branching and flowering begin when the shoots are much shorter late in the season. As a result, shoots of equal height have a much smaller proportion of edible material per shoot late in the season than near the beginning. There are very considerable variations in individual stalks, but these statements fairly represent the average results.

In commercial canning operations much grading and trimming is necessary in order to secure a product of uniform appearance and high quality. According to Cruess (*5*), the loss in weight through grading and trimming may amount to 50 percent of the gross weight as cut. Some canneries utilize a portion of this material by shredding and canning as soup stock, but the major portion is discarded. It is obvious from the chemical analyses here reported that the basal portions contain considerable amounts of food material. It has been made evident from the cooking and canning tests that the basal portions even of older stalks are palatable and very acceptable in texture after the cortex and pericyclic fibers have been removed.

It should be understood that the results here reported were obtained for the most part from a single season's work with material grown in only one locality and under only one set of weather conditions. It is undoubtedly true that repetition of the work under different environmental conditions would lead to somewhat different results. It is very probable that many factors, such as cultural methods, fertility of the soil, and character and amount of fertilizer applied, influence the development of asparagus and modify its composition in some degree. Much further work will be necessary before anything approaching a complete understanding of the effects of these factors can be reached.

SUMMARY AND CONCLUSIONS

A study has been made of the composition and the canning and cooking qualities of the different regions, from base to tip, of developing asparagus shoots of various ages and heights, by a method which consisted in subdividing the shoots into a number of short segments

which were separately subjected to chemical analyses and to pressure, cooking, and canning tests.

Moisture content varies continuously, from base to tip, in shoots at all stages of development. There is a region of maximum moisture content at the base in the very young shoot, which shifts upward with increase in height of the shoot. In shoots 4 inches in length, cut 1 inch below the soil surface, moisture content is highest in the basal inch; in shoots 8 inches high, it is highest 4 inches above the base; in 18-inch shoots, 10 inches above the base; and in 36-inch shoots, 24 inches above the base. The moisture content of the growing tip did not vary greatly in shoots of different heights up to 36 inches. The moisture content of the basal region rapidly decreases with increasing height, reaching a comparatively low level in shoots 72 inches in height.

Sugar content was highest in the basal segment and decreased toward the tip in stalks at all stages of growth.

Total nitrogen was highest in amount in the tip and decreased progressively in amount toward the base in shoots at all stages of development. The total nitrogen of the terminal segment did not vary greatly in shoots up to 18 inches in height, and it varied very little in any of the basal segments.

The titratable acidity and total astringency showed a tendency to increase toward the tip. The values were rather low in both cases for stalks of all heights.

The resistance of the stalk to pressure, as measured by the pressure tester used, was in all cases greatest at the base and decreased toward the tip in all stalks, at least in those up to 36 inches high. The resistance to pressure at the tip did not vary greatly in stalks of differing height. The basal portion increased tremendously in its resistance to pressure as the stalks grew taller, as a result of the development of a ring of fibers just beneath the cortex.

Pressure tests before and after canning showed that there was an enormous softening of the tissues of the shoot during the heating process. The difference in the values of the pressure tests before and after canning did not vary greatly either with height of the segment above the base or with stalks of differing height.

It was considered that the quality of the canned product was richer and more pleasing at the tip than at any point below this, even at the point where the moisture was highest. The flavor and richness did not vary greatly at the tip in stalks of differing height, but there was considerable variation at the base. The taller stalks were judged to be less pleasing to the taste. These results agreed essentially with those obtained by cooking the fresh material. The appearance and physical character varied greatly at the tip as well as at the base. The diameter near the tips became much less as the stalk grew taller, and the appearance was less attractive, owing to development of green color and to darkening after heating, as in canning and cooking. As the stalks grew taller the basal segments became hard and woody because of the continued development of the fibrous structure of the stalk.

Of stalks 4, 8, 18, and 36 inches tall, the amount of material per stalk which would make an acceptable food product seemed to be greatest in the stalks 18 inches tall. To determine the height more exactly tests on stalks of intermediate height should be made.

The quality of the canned and freshly cooked product of shoots 4 inches tall did not vary greatly as the cutting season advanced. However, this did not hold for shoots of greater height, owing to the tendency to become fibrous at the base and the tendency to branch and flower at a lower height late in the season. This made the taller stalks much less desirable late in the season than stalks of equal height harvested early in the season.

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U. S. GOVERNMENT PRINTING OFFICE: 1935

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