ABERRATIONS IN THE CHEMICAL COMPOSITION OF PEAS FROM PLANTS AFFECTED WITH ROOT ROT [1]

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INTRODUCTION

In 1932 Horsfall, Kertesz, and Green (*9*) [2] reported some physiological observations and a few chemical analyses of peas from normal and root-rot-affected plants. Since these results showed significant differences in the proportion of dry matter as well as in the constitution of the dry matter itself, they were used as the basis for a further study extending through the 1932 and 1933 seasons. The present paper deals with the progressive chemical changes that take place during the harvest season in peas from diseased vines as compared with those from normal vines growing under similar conditions.

The literature is sprinkled with references to the influence of a fruit disease on the composition of the fruit, but references to the influence of a root disease upon the composition of the fruit are rare. Dungan (*6*) reported briefly that corn root rot reduced the specific gravity of the grain as well as the proportion of total sugars and ether extract. The nitrogen content of the tissue seemed to be increased by the disease. Linford (*15*) found that the dry matter content of pea plants affected with wilt was higher than that of normal plants. Culpepper and Magoon (*4*) studied the effect of artificial root pruning, which might be similar to the effect of root rot, on the chemical composition of sweet-corn kernels. They found that total and alcohol-insoluble solids and acid-hydrolyzable higher carbohydrates in sweet-corn grains increased with the extent of root pruning performed at the time of silking. Moreover, "the rate of maturing seemed to be slightly increased."

MATERIAL AND METHODS

SAMPLING TECHNIC

The variety Perfection was used throughout the experiments. The technic employed in collecting infected and healthy plants and sampling them has already been fully discussed (*7*). It may be described briefly as follows: In 1931, peas (*Pisum sativum* L.) were obtained from yellowed vines and from normal-looking vines growing near-by in the same field. This conscious selection of diseased and healthy samples gave large differences in the results. In 1932, a plot of normal soil was artificially infested with "pea-sick" soil. Thus normal and diseased plants could be grown on contiguous plots under otherwise identical conditions. The 1933 samples came from the same plots as the 1932 samples.

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[2] Reference is made by number (italic) to Literature Cited, p. 813.

In all of these studies samples for analysis were drawn from the population at intervals during the season. This method of obtaining samples gives data that can be arranged in trend curves which show their significance at a glance without resort to statistical analysis.

In all years whole-plant samples of the two lots were broken at the ground line before 8 a.m. and taken to the laboratory. Generally, not more than 3 hours elapsed from the time the plants were pulled until all determinations on the fresh peas were finished. Immediately after hand-shelling, each sample was passed through a set of hand sieves corresponding to those used by canners (*7*), and the weight of each fraction was recorded. Samples for analysis were taken from each of the sieve sizes in all cases in which sufficient peas were available. Data on the various sieve sizes are valuable for certain purposes, particularly to canners who are interested in certain sized peas, but they are somewhat unsatisfactory for giving a picture of the situation in a handful of unsifted peas. This difficulty was obviated by taking a weighted average of the determinations for the various sizes. This figure is comparable to average sieve size as already described (*7, p. 7*). It is a simple arithmetical calculation involving the multiplication of the number for the chemical constituent in question by the percentage by weight of peas in that size. These numbers for all sizes are then summed and divided by the total percentage of peas in the sizes used. This weighted average determination undoubtedly represents more nearly the true condition in a handful of unsifted peas as obtained from the field than a single determination, as it is essentially a method of replication. It is, however, more than a series of replicated determinations on the original unsifted sample as it gives an idea of the situation in the various components of the original as well.

CHEMICAL ANALYSES

For the determination of the dry matter in the peas, 25- or 50-g samples were dried at 95° to 98° C. for 2 days, after which several controls failed to show a further decrease in weight. Ash, nitrogen, and crude fiber were determined by the official methods (*1*). The determinations of the two fractions of nitrogen were made by extracting the ground peas with hot 80-percent alcohol until the extract failed to give a reaction for sugars. In the extract the sugars were determined by the procedure described earlier (*14*), Bertrand's method and the recalculated tables (*11*) being used. Starch determinations were performed on the alcohol-insoluble residue, using takadiastase followed by acid hydrolysis (*12*). The figures for total carbohydrates in 1931 were obtained by direct acid-hydrolysis of the dried peas by the method given by Boswell (*3*). The figures for total carbohydrates in the peas of 1932 were obtained by subtracting the percentage of nitrogen$\times$6.25 from the percentage of alcohol-insoluble residue and adding the percentage of total sugars; consequently they include crude fiber.

ORGANISMS ISOLATED

Isolations from diseased roots on the experimental plants show that *Pythium* spp., favored by a wet May, were the primary invaders in the roots in 1931 and 1933 and that *Rhizoctonia solani* Kühn, favored by a dry May, was the primary invader in 1932 (*7, 8*). Both organisms were found in the roots during each season, so that the symptom complex called root rot cannot be ascribed to the action of a single organism. Technically the data might have been more widely usable if they had been taken from plants inoculated with single organisms, but in other respects the data are more applicable because they deal with the actual situation as it exists in the field and as it confronts the canner.

If *Aphanomyces euteiches* Drechs. occurred it was not important in in the etiology of the complex. The plants were considerably injured by aphids in 1933, and the onset of the disease was much earlier in that year than in 1932, so that the plants were infected for a longer period.

WEATHER CONDITIONS

In all 3 years June was dry, with no appreciable rainfall until 2 or 3 days after sampling began. A drought-breaking rain fell on July 3 in 1931, on July 1 in 1932, and on June 30 in 1933. In table 1 the rainfall is shown for the three seasons in which the samples were taken. No further rain fell during the harvest season in 1931, so that the peas were very hard by July 6. The same was essentially true in 1933, but in 1932 the harvest season after July 1 was moist. For commercial use the peas would have been ready for a fancy pack on July 2 in 1931, on July 5 in 1932, and on July 1 in 1933.

TABLE 1.—*Daily precipitation (inches) during the pea harvest season at Geneva, N.Y., in 1931, 1932, and 1933*

Year	June				July														
	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1931	----		----	----	----	----	0.99	0.04	----	0.03	0.04	(1)	(1)	0.77	0.07	0.01	----	0.20	----
1932	0.33	----	----	(1)	2.11	0.05	.04	.95	----	----	.18	0.44	(1)	(1)	.55	----	(1)	.14	----
1933	----	----	(1)	0.37	.01	(1)	.30	----	----	----	----	.01	0.06	(1)	----	----	----	----	----

[1] Trace.

PRESENTATION OF RESULTS

DRY MATTER

The main chemical effect of the root-rot complex on the pea plant is an increased dry-matter content resulting from a curtailment of the power of water absorption through the diseased roots. Consequently, peas from plants affected with root rot contain less water than peas from healthy plants. In table 2 and figure 1 the results of the dry-matter determinations on Perfection peas for 1931, 1932, and 1933 are presented. This table also contains the percentages by weight of peas in certain sizes on the different sampling dates. These figures have been used to calculate the average sieve size of the peas (7), which was used as a basis for calculating the average content of the different constituents, as described on page 799.

Since in 1931 the diseased peas were taken from spots showing symptoms of root rot, while the control samples were obtained from an adjacent spot where relatively disease-free plants were growing, the differences between the two samples were much larger than in later years when the samples were obtained from contiguous plots one of which was contaminated with "pea-sick" soil. The effects of the abnormally dry season of 1933 are apparent in the dry-matter curves, which show that the dry-matter content of the peas at the very beginning of the season (June 30) was higher than at the end of

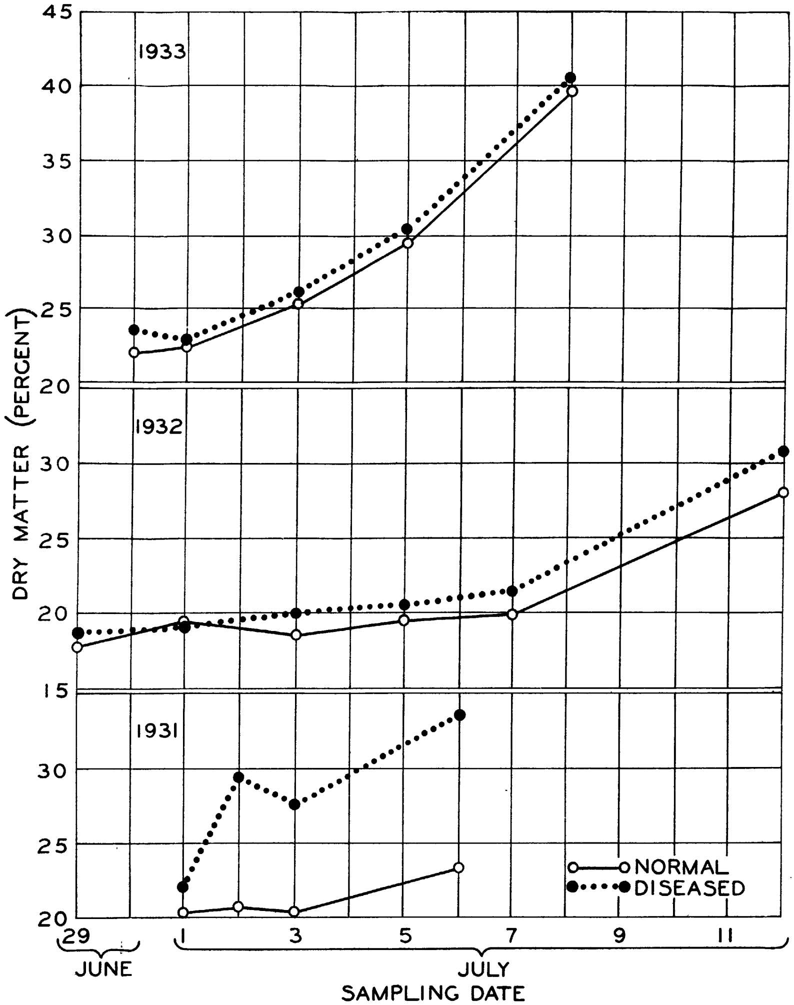

FIGURE 1.—Dry matter (percent) of normal and diseased Perfection peas in 1931, 1932, and 1933.

the canning season (July 7) in 1932. The quality of all peas harvested in 1933 was poor even when the peas were in "prime" condition.

TABLE 2.—*Average sieve size, distribution of sizes, and dry matter content*[1] *of normal and diseased Perfection peas in 1931, 1932, and 1933*

Date of harvest	Normal peas			Diseased peas		
	Sieve size	Distribution of sizes, by weight	Dry matter	Sieve size	Distribution of sizes, by weight	Dry matter
1931		*Percent*	*Percent*		*Percent*	*Percent*
July 1	2	21.3	18.91	--------	22.2	20.89
	3	23.8	19.78	--------	37.5	22.07
	4	27.2	21.39	--------	26.2	23.35
	5	9.7	21.78	--------	6.1	23.63
Average	2.94	--------	20.33	3.02	--------	22.25
July 2	2	18.7	18.91	--------	26.9	30.79
	3	28.6	20.14	--------	19.2	29.81
	4	40.3	21.37	--------	43.9	28.85
	5	10.5	23.34	--------	--------	--------
Average	3.40	--------	20.75	3.31	--------	29.64
July 3	2	4.5	18.68	--------	--------	--------
	3	28.9	19.80	--------	26.5	28.70
	4	41.0	20.71	--------	45.4	27.20
	5	21.8	22.11	--------	23.3	28.21
Average	3.75	--------	20.66	3.92	--------	27.87
July 6	3	12.2	21.32	--------	25.1	35.26
	4	47.4	23.32	--------	38.7	32.84
	5	29.5	24.61	--------	19.3	33.11
Average	4.24	--------	23.46	3.62	--------	33.62
1932						
June 29	2	29.60	17.06	--------	33.30	17.93
	3	18.08	18.01	--------	27.70	18.69
	4	12.16	18.92	--------	13.80	19.71
	5	3.54	19.57	--------	2.80	20.80
Average	2.06	--------	17.80	2.41	--------	18.63
July 1	1	11.15	16.49	--------	15.30	16.22
	2	17.45	17.23	--------	19.10	17.07
	3	27.65	17.66	--------	20.90	18.85
	4	26.45	18.79	--------	20.40	19.86
	5	15.35	20.10	--------	21.60	20.45
	6	1.95	20.73	--------	2.70	22.35
Average	3.23	--------	19.53	3.23	--------	19.21
July 3	1	4.85	16.37	--------	4.30	--------
	2	7.45	17.12	--------	8.55	17.14
	3	13.10	17.29	--------	10.20	18.17
	4	27.10	18.15	--------	23.60	19.54
	5	39.10	19.59	--------	40.80	20.55
	6	8.40	21.00	--------	12.55	21.39
Average	4.08	--------	18.37	4.31	--------	19.85
July 5	2	2.05	16.18	--------	3.87	17.17
	3	9.92	17.37	--------	5.40	17.93
	4	14.40	18.90	--------	14.00	19.13
	5	36.80	18.90	--------	34.20	20.45
	6	33.50	21.13	--------	39.60	21.36
Average	4.80	--------	19.46	4.92	--------	20.36
July 7	2	2.10	16.21	--------	1.72	17.99
	3	4.20	17.36	--------	2.86	17.22
	4	9.30	19.06	--------	6.90	18.84
	5	27.50	18.70	--------	27.60	21.06
	6	55.00	21.05	--------	59.60	22.77
Average	5.23	--------	19.94	5.37	--------	21.75

[1] In this table only the percentages of sizes and dry-matter content of the samples used for chemical work are given. For further details see (9) for the 1931 and (7) for the 1932 samples.

TABLE 2.—*Average sieve size, distribution of sizes, and dry matter content of normal and diseased Perfection peas in 1931, 1932, and 1933*—Continued

Date of harvest	Normal peas			Diseased peas		
	Sieve size	Distribution of sizes, by weight	Dry matter	Sieve size	Distribution of sizes, by weight	Dry matter
		Percent	*Percent*		*Percent*	*Percent*
July 12	3	0.94	23.34		0.95	27.35
	4	5.66	25.01		3.55	29.50
	5	24.85	27.25		27.49	30.80
	6	67.80	28.70		67.63	31.11
Average	5.58		27.92	5.61		30.92
1933						
June 30	1	8.00	19.04		6.35	18.47
	2	12.62	20.01		10.35	20.18
	3	32.30	22.68		29.45	21.33
	4	37.30	22.74		35.86	22.96
	5	8.78	23.89		16.98	23.96
	6				1.01	24.29
Average	2.25		21.95	3.50		23.59
July 1	1	5.83	17.62		4.20	
	2	11.73	20.98		7.00	19.80
	3	36.80	22.41		21.60	21.74
	4	31.52	23.41		40.50	23.16
	5	13.60	23.94		23.65	23.74
	6	.52			3.05	24.77
Average	3.37		22.49	3.81		22.79
July 3	1	2.48	22.31		1.84	
	2	5.48	23.12		2.35	23.27
	3	21.10	24.50		11.52	23.86
	4	48.62	25.25		46.13	25.46
	5	20.00	26.85		36.22	26.24
	6	2.32	27.04		3.14	27.25
Average	3.85		25.26	4.26		25.88
July 5	1	2.34	27.57		2.80	26.05
	2	5.45	28.35		5.40	30.23
	3	17.64	29.03		16.20	30.77
	4	43.33	29.87		37.10	29.70
	5	27.56	29.76		33.20	31.24
	6	3.68	30.31		5.30	30.31
Average	4.02		29.57	4.08		30.34
July 8	1	9.98	36.15		9.31	34.85
	2	14.22	35.53		13.35	35.40
	3	22.45	36.70		20.19	35.87
	4	35.15	39.75		35.45	40.19
	5	14.65	47.05		18.85	50.02
	6	3.55	53.43		2.85	58.28
Average	3.41		39.66	3.51		40.54

ASH

The results of the ash determinations obtained in the three seasons are presented in figure 2. In 1931 the ash content of the dry matter in the peas from root-rot-affected plants was lower than that in peas from healthy plants. When the results are calculated on the basis of fresh peas, the ash content of the diseased peas is higher because the diseased peas had a higher dry-matter content than the normal peas.

In 1932 and 1933 the ash content of the dry matter was again lower in the diseased peas. The moist season of 1932 gave only slight differences in the dry-matter content of the two lots of peas; accordingly the ash content of diseased peas calculated on the fresh-material basis was the same as, or a trifle lower than, that in the normal ones. In 1933, however, when the dry-matter content of both lots of peas was much higher than in previous years, the ash content was actually lower in the diseased peas, even on a fresh-material basis.

It was found by Sayre, Willaman, and Kertesz (*17*) that the ash content of normal growing peas increased almost proportionally with the increase in the dry-matter content, whereas it remained about constant or decreased slightly in the dry material itself as the season advanced. The same has been found in the present study in all 3 years, the fresh peas showing a fairly regular increase in ash content except for July 2 in 1931 and July 3 and 5 in 1932. It is believed, as

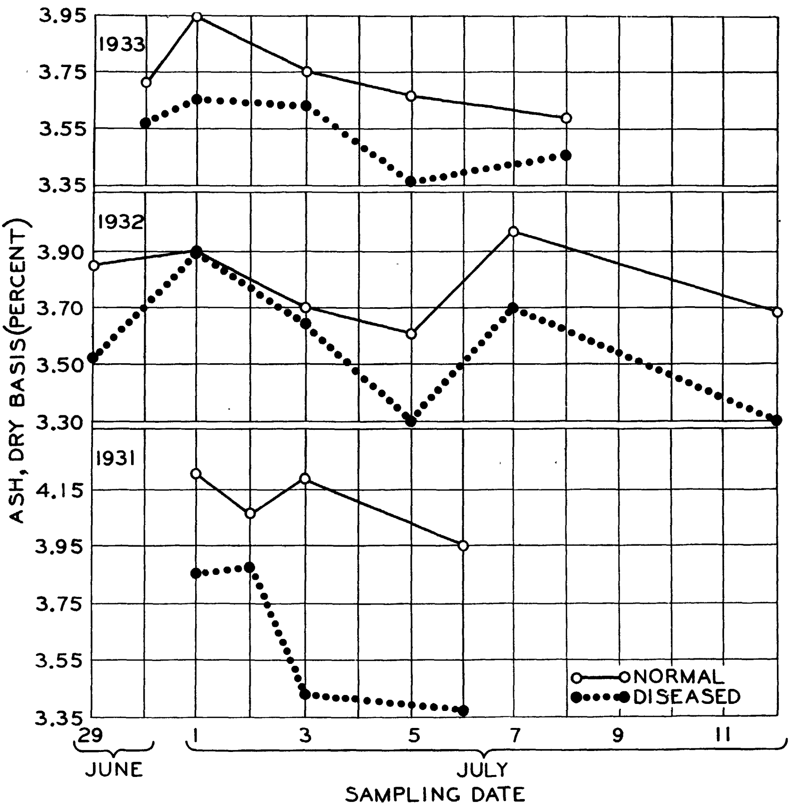

FIGURE 2.—Ash content of the dry matter of normal and diseased Perfection peas in 1931, 1932, and 1933.

suggested by Horsfall, Kertesz, and Green (*9*), that the decrease on these days was due to the heavy rains which fell on July 3, 1931, and on July 3 and 4, 1932. These rains caused the peas to absorb water and dry matter from the vines, which resulted in rapid swelling, as can be seen from the figures for average sieve size given in table 2. Ash uptake lagged behind, the result being a lower ash content in the dry matter for a time.

PROTEIN

The results obtained on the nitrogen content of the peas are presented as percentage of protein (the percentage of total nitrogen multiplied by the factor 6.25). Kertesz and Green (*14*) pointed out that although a fraction of the nitrogen in peas is present in nitrogenous compounds other than proteins, the actual weight of all nitrogenous compounds is nearer to nitrogen×6.25 than to the weight of nitrogen found.

Horsfall, Kertesz, and Green (*9*) found a lower nitrogen content in the dry matter of diseased Alaska, Advancer, and Perfection peas than in the corresponding normal samples. Because of the large differences in the dry-matter content, this relation was reversed when the results were calculated on a fresh basis, however. The nitrogen

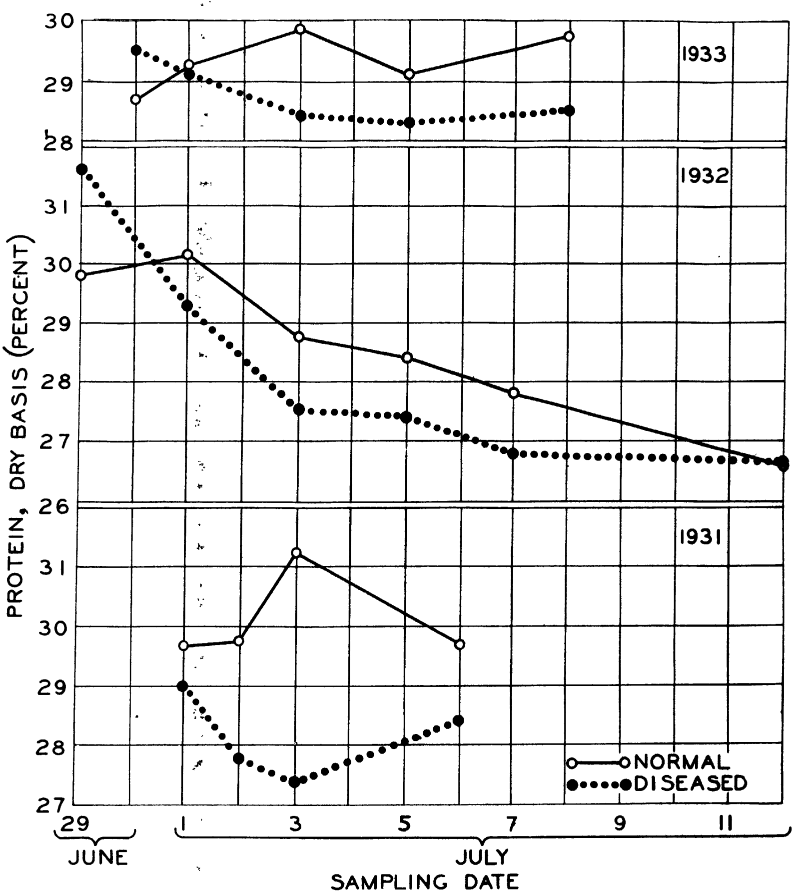

FIGURE 3.—Protein (N×6.25) content, on a dry basis, of normal and diseased Perfection peas in 1931, 1932, and 1933.

determinations on the 1932 and 1933 Perfection peas showed the same relation for nitrogen×6.25 (fig. 3). Except in the first sample in both the 1932 and 1933 seasons, the results confirm the observation that the protein content of the dry matter is lower in the diseased than in the normal peas.

During the growth and ripening of peas, nitrogenous compounds soluble in hot 80-percent alcohol are transformed into insoluble ones (*3*, *10*). Since this transformation is a typical and constant phenomenon in growing peas, the ratio of insoluble nitrogen to soluble nitrogen has been proposed by Muttelet as an index of ripening (*16*). It was of much interest, therefore, to obtain an insight into the changes in the two fractions of nitrogen in the diseased peas as contrasted with those in normal ones. Table 3 shows the results obtained on the 1932 peas.

The ratios of insoluble to soluble nitrogen were slightly higher for the diseased samples on the first 2 days of sampling, but were lower on July 5. In the latter part of the season 1 ratio was higher and 1 lower. Consequently, the transformation of (mostly) nonprotein nitrogen to protein nitrogen was not significantly more rapid in the diseased peas than in the normal peas.

TABLE 3.—*Weighted average soluble and insoluble nitrogen content of normal and diseased Perfection peas in 1932*

Date of harvest	Normal peas			Diseased peas		
	Soluble N	Insoluble N	Insoluble N / Soluble N	Soluble N	Insoluble N	Insoluble N / Soluble N
	Percent	*Percent*		*Percent*	*Percent*	
July 1	0.158	0.714	4.52	0.153	0.718	4.69
July 3	.149	.716	4.81	.145	.729	5.03
July 5	.108	.776	7.19	.122	.741	6.07
July 7	.080	.814	10.18	.079	.860	10.89
July 12	.038	1.155	30.39	.046	1.277	27.76

CARBOHYDRATES

Since it had been shown (*9*) that the content of both nitrogen and ash in the dry matter of diseased peas is lower than that of normal peas, a search was made for some constituents the proportion of which is higher in the diseased peas and which would thus account for the remainder of the dry matter. Therefore, the 1931 samples were analyzed for total carbohydrates, acid hydrolysis being used to convert the higher carbohydrates into sugars. The results (table 4) show that the content of total carbohydrates is higher in the root-rot-affected peas on both a fresh- and dry-weight basis than in the normal peas. The increase in carbohydrates in the dry matter of diseased peas practically balances the decrease in ash and nitrogen. Additional crude-fiber determinations showed the same general trend as did total carbohydrates, although the differences in this constituent were somewhat inconsistent when expressed on the dry-matter basis.

TABLE 6.—*Weighted average total carbohydrate content (percentage of sugars plus acid-hydrolyzable higher carbohydrates) on fresh and dry basis of normal and diseased Perfection peas, 1931*

Date of harvest	Normal peas		Diseased peas	
	Fresh basis	Dry basis	Fresh basis	Dry basis
	Percent	*Percent*	*Percent*	*Percent*
July 1	9.13	44.89	10.52	47.29
July 2	8.82	42.49	14.24	48.05
July 3	9.18	44.45	15.05	54.00
July 6	10.84	46.19	17.52	52.09

In 1932 an elaborate study of the carbohydrates was made. The season was well suited for such studies since peas of good quality could be obtained and the effect of root rot on the peas in the infested plot was apparent but not severe enough to upset entirely their normal functions, as often happens. The results of the chemical determinations are presented in table 5. The determinations of reducing sugars are omitted because the content was so low (0.15 to 0.31 percent) and because there appeared to be no difference between the normal and diseased peas in respect to these constituents. To conserve space the figures for higher carbohydrates, including crude fiber, also are omitted from the table since these were obtained by subtracting insoluble nitrogen × 6.25 from the alcohol-insoluble residue. For the same reason, the results are discussed only as daily weighted averages on the basis of the fresh peas.

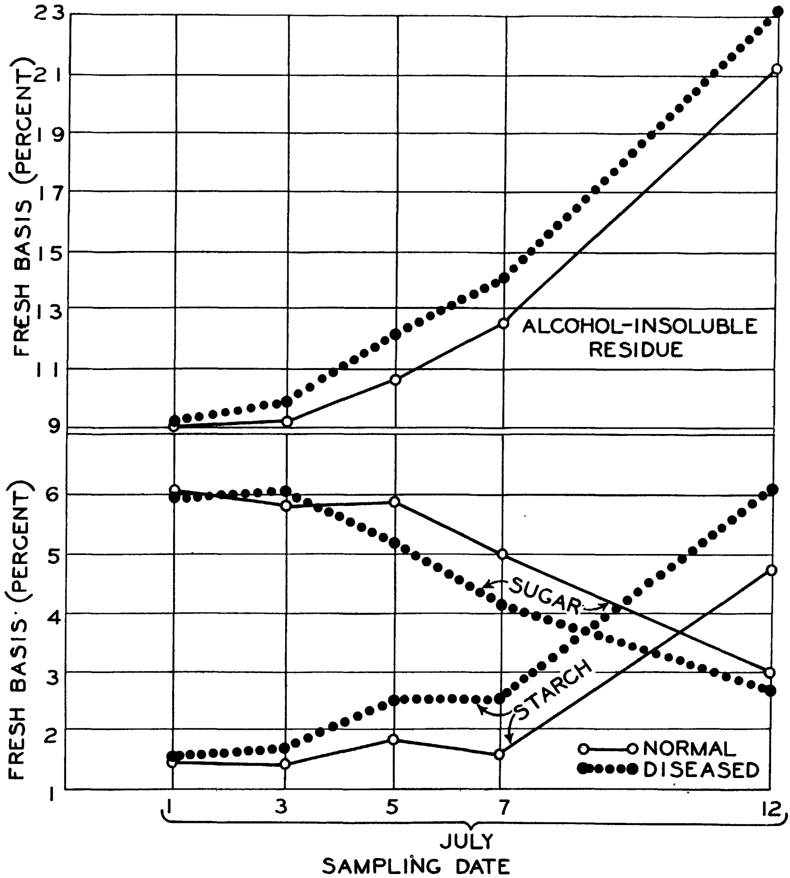

FIGURE 4.—Daily average starch, sugar, and alcohol-insoluble solids content of normal and diseased Perfection peas in 1932.

The total sugar content of the 1932 Perfection peas decreased through the sampling period. The peas were in prime condition for canning on July 5, before the sucrose content of the normal peas has decreased materially. The diseased peas lost only about 11 percent of their average sugar content from July 1 to July 5. After that date the sucrose content of the peas diminished rapidly and was always lower in the peas from diseased plants than in those from normal plants, not only in the daily averages as given, but also when compared size for size. The daily average sugar content of normal and diseased peas is shown in figure 4.

TABLE 5.—*Carbohydrate constituents of fresh normal and diseased Perfection peas, 1932*

Date of harvest	Size no.	Normal peas						Diseased peas					
		Total sugars	Starch	Total carbohydrates	Alcohol-insoluble solids	Higher carbohydrates[1] / sugars	Starch / sugars	Total sugars	Starch	Total carbohydrates	Alcohol-insoluble solids	Higher carbohydrates[1] / sugars	Starch / sugars
		Percent	*Percent*	*Percent*	*Percent*			*Percent*	*Percent*	*Percent*	*Percent*		
July 1	1	4.90	1.47	7.04	6.35			4.91	1.46	5.38	6.65		
	2	5.57	1.22	8.54	7.15			5.49	1.53	7.45	7.27		
	3	5.86	1.51	9.55	8.00			5.77	1.24	9.97	8.71		
	4	6.06	1.31	10.77	9.34			5.90	1.18	11.04	9.91		
	5	5.73	1.10	11.27	10.50			5.69	1.68	11.71	11.12		
Average		6.062	1.449	9.68	9.033	0.60	0.239	5.917	1.468	9.36	9.144	0.61	0.248
July 3	1	5.94	1.28	8.94	6.84			6.74	1.29	9.47	6.77		
	3	6.18	1.09	10.04	7.75			6.18	1.23	9.58	7.40		
	4	5.78	.95	10.04	8.50			6.51	1.63	11.40	9.16		
	5	5.93	1.96	11.73	10.56			5.91	1.90	11.97	10.78		
	6	5.48	1.94	11.80	11.70			5.74	1.68	13.30	12.94		
Average		5.761	1.442	10.80	9.112	.88	.250	6.056	1.667	11.53	9.846	.90	.275
July 5	2							6.41	1.39	9.44	7.20		
	3	6.35	1.37	9.57	7.55			5.85	1.73	10.12	8.21		
	4	6.18	1.75	10.75	8.76			5.98	1.35	10.72	9.35		
	5	5.93	1.80	11.63	10.42			4.97	2.65	12.74	12.58		
	6	5.50	1.96	13.03	12.96			5.17	2.57	13.67	14.00		
Average		5.877	1.856	11.78	10.664	1.00	.316	5.253	2.464	12.55	12.094	1.39	.469
July 7	2							5.58	1.56	11.44	10.48		
	3	5.51	1.11	9.26	8.02			5.05	1.30	9.82	9.13		
	4							5.59	1.40	11.68	10.78		
	5	5.56	1.45	12.66	11.53			4.73	2.04	12.45	12.86		
	6	4.70	1.68	12.92	13.70			3.93	2.82	13.66	15.36		
Average		5.001	1.554	12.66	12.560	1.53	.311	4.187	2.480	13.03	14.016	2.12	.592
July 12	4	3.04	3.48	15.57	18.76								
	5	2.43	5.39	17.34	21.85			2.25	7.41	20.26	25.70		
	6	3.11						2.94	5.74	16.65	21.82		
Average		3.015	4.665	17.11	21.19	4.67	1.547	2.678	6.079	17.69	23.22	5.61	2.270

[1] Including crude fiber.

The sugar content was lower in the diseased samples on all dates, except July 3. During the later growing season the difference in the percentage of sugars in the two lots of peas was almost constant, although this difference expressed as percentage of the total sugar content increased materially as a result of the rapidly decreasing proportion of sugars in the peas. The difference between the sugar content of the normal and the diseased peas is even larger when the results are expressed on the dry-matter basis. On the 5 days when samples were taken, the sugar content of the diseased peas was lower by 0.77, 2.71, 14.57, 23.41, and 14.09 percent, respectively, than the sugar content of the normal peas. These figures well express the progress of the differences between the two lots of peas.

Higher Carbohydrates

The percentage as well as the absolute amount of starch increases in the peas during growth. It is apparent from table 5 and figure 4 that the increase in the starch content was more rapid in the diseased than in the normal peas. In the normal peas there seems to have been only a small variation in the starch content until after July 7, when it increased sharply. In the diseased peas, however, the increase was quite consistent from the second sampling date.

There are other higher carbohydrates which show even more striking differences between the peas from normal and diseased plants. These figures are obtained by subtracting the percentage of soluble nitrogen$\times$6.25 from the percentage of alcohol-insoluble solids. This fraction, which includes starch, dextrines, pentosans, pectins, fiber, and other higher carbohydrates, shows by July 5 a definite difference between the two lots of peas. The differences are much larger than those which the starch content alone could account for. This can be easily proved by subtracting the percentage of starch from the values. The resulting figures still show significant differences in higher carbohydrates other than starch between the normal and diseased peas.

During recent years it has been customary to calculate and apply different "indexes" to the quality of horticultural products. Recently the importance of the proportions of starch and sugar in relation to flavor and quality of sweet corn has been emphasized. Muttelet (*16*) proposed this ratio for determining the quality of peas. In figure 5 the starch-sugar ratios and also the total higher carbohydrate-sugar ratios are presented. As would be expected, the total higher carbohydrate-sugar ratio shows a more rapid increase with ripening and also larger differences between the peas from normal and diseased plants than does the starch-sugar ratio.

It has been shown that in peas sugars decrease, while starch and other higher carbohydrates, fiber, and protein nitrogen increase during growth (*2*, *10*). These constitutents all contribute to the alcohol-insoluble solids of the peas which contain all the "undesirable" constituents of the peas (starch, higher carbohydrates, fiber, insoluble nitrogen, etc.) from the canner's standpoint. This fraction seems to offer a dependable and simple way to evaluate the quality of raw and canned peas (*13*). Figure 4 shows the percentage of alcohol-insoluble residue in the two lots of peas.

The value for alcohol-insoluble solids in the normal peas lagged behind that in the diseased peas by about 1 day, the two curves being parallel. Naturally, the differences in the absolute amount and percentage of alcohol-insoluble solids on the dry-matter basis are much larger than when calculated on the basis of the fresh peas.

DISCUSSION

It is not the purpose of this paper to deal with the effects of root rot on the physiology of the pea plant itself; a preliminary discussion of that point (*9*) has already been presented. Nor is it the purpose to offer a complete explanation of the established differences in the chemical composition of the peas caused by the disease. Knowledge of the mechanism of plant nutrition and assimilation is too meager

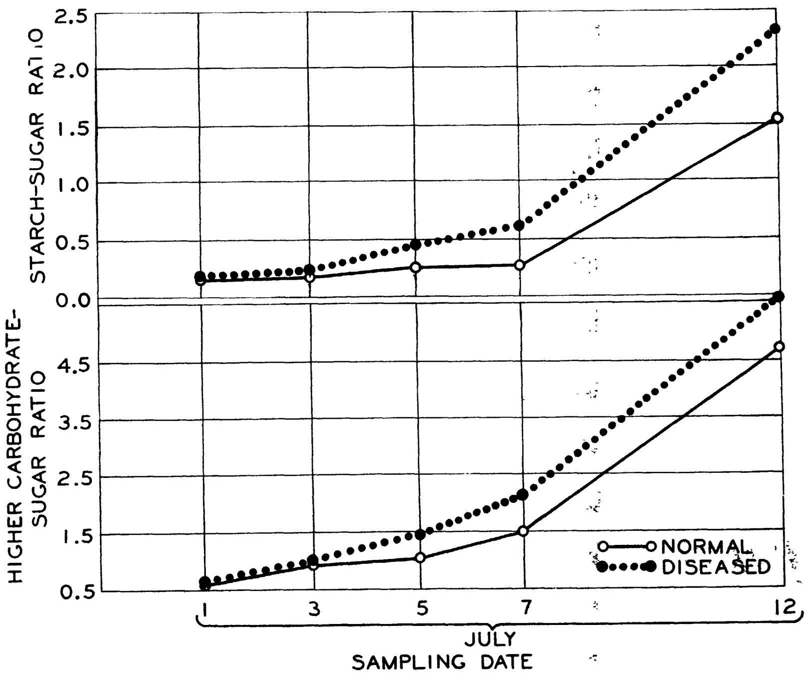

FIGURE 5.—Higher carbohydrate-sugar and starch-sugar ratios of normal and diseased Perfection peas in 1932.

to warrant much speculation regarding the influence of root rot on these processes. Nevertheless, a few points are obvious enough to permit the drawing of some conclusions.

It may be assumed that the primary action of root rot on the pea plant is to curtail the water supply. The obvious results of this are repressed growth or stunting of the diseased plants, the setting of fewer pods per plant, and a lower yield.

As previously stated, the dry-matter content of the diseased peas was higher in all samples taken throughout the three harvest seasons. One might infer that this was due directly to the lowered water intake by the diseased roots. The evidence shows, however, that the higher dry-matter content was due in part, at least, to the presence of more solid material in the average pea from a diseased plant. The diseased pea grows larger (*6*) and is drier; it must, therefore, contain more solid material than a normal pea.

Since a lower ash and nitrogen content was found in the dry matter of the diseased peas, these two constituents can play no part in an explanation of the higher dry-matter content. Both of these constituents are absorbed through the root system of the plant. When this is damaged by the attacking fungi, the ash and nitrogen uptake is inhibited just as the water intake is. If, as Curtis (*5*) suggests, ash and nitrogen move chiefly through the living tissues of the plant, the destruction of the cortex of the root would be reflected directly in a lessened uptake of these two constituents.

The fact that total carbohydrate content is greater in diseased peas than in normal ones admits of several explanations. The metabolism of the plant may be so upset by the formation of some toxic material in the diseased roots that the synthesis of carbohydrates becomes accelerated. No evidence of this is available in the case of pea root rot, however. It may be that there is a more vigorous translocation of carbohydrates into the ovules, thus leaving relatively less in the plants, or the partial or complete death of the living parts of the root system may prevent it from utilizing as much carbohydrate as otherwise, thus leaving an excess to be moved into the ovules, causing the abnormal enlargement reported (*7*). This hypothesis involves no postulation of a disturbance in the process of translocation.

Of considerable importance is the fact that diseased peas contain relatively less of the lower carbohydrates and relatively more of the higher carbohydrates than normal peas. The excessive enlargement observed (*7*) cannot explain the lower sugar content of the diseased peas, although such an explanation has been suggested. The difference between the average volume of normal and diseased peas on July 5, 7, and 12 was 3.16, 2.18, and 2.29 percent, respectively, while the sugar content of the diseased peas on the same dates was lower by 10.62, 16.28, and 11.18 percent than that of normal peas. Thus, the lower sugar content of the diseased peas cannot be ascribed to a "dilution" of the sugar by an abnormal enlargement.

As already shown (*7*), the peas used for the chemical analyses enlarged until about July 9 in 1932. The normal peas showed no increase in the percentage of starch up to July 7, although naturally the absolute amount of starch per pea increased as the size of the pea increased. Between July 7 and July 12, starch content increased sharply as the peas dried out in approaching the seed stage. In the diseased peas, however, the starch content had already begun to increase by July 5, so that the chemical composition showed signs of approaching the seed stage much earlier than normal.

Carbohydrate changes play an important part in the ripening of green peas. During the early stages of development, the sugar content of peas increases (*2*, *10*). Soon afterward a sharp decrease in the content of total sugars coincident with an increase in higher carbohydrates sets in and continues almost until the peas dry out. Specifically, the lower carbohydrates, like sugars, are changed into starch and other higher carbohydrates. Evidence presented herein indicates that this process proceeds more rapidly in the diseased than in the normal peas. Since polymerization of carbohydrates results in the production of free water, the physiologically drier conditions existing in the diseased peas would tend to shift the equilibrium in the direction of a smaller water requirement for the system. Thus, the formation of a larger proportion of higher carbohydrates in the peas on diseased plants might be due to a hastening of polymerization by the drier conditions.

Although the synthesis of nitrogenous compounds should be affected in a way similar to that of the carbohydrates, the results on the two fractions of the nitrogenous compounds as presented in table 5 do not indicate that it is. There appears to be no indication of a significantly quicker rate of protein formation in the diseased than in the normal peas. Since the nitrogen supply to diseased peas is inadequate, however, one should not expect the same behavior of proteins as of the carbohydrates, an excess of which seems to be transferred into the ovules.

All the established differences in the chemical composition of peas from normal and diseased plants have a direct bearing on the quality of the green peas as harvested for canning. The relative rate at which the sugar in the peas changes into higher carbohydrates determines the changes in quality and thus the time at which the crop is in prime condition for canning. Therefore, the fact that there was a higher total carbohydrate and lower sugar content in the diseased than in the normal peas indicated essential differences in quality between the two lots.

SUMMARY

The chemical composition of peas harvested from plants affected by the root-rot complex is different from that of normal plants of the same age and history grown in the same field.

The injured root system seems to curtail the water, nitrogen, and ash supply, which results in the setting of peas with a lower water content and a lower ash and nitrogen content in the dry matter.

The disease seems to favor quicker translocation of carbohydrates into the ovules. This may explain the abnormal enlargement of the peas from diseased plants as compared with those from normal plants.

The larger proportion of higher carbohydrates in diseased peas is presumably due to the hastening of polymerization by the lower water content.

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