# IMPROVEMENT IN THE CHEMICAL COMPOSITION OF THE CORN KERNEL.[1]

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THE many different uses which are made of corn and the enormous value of the crop to the United States may certainly be deemed sufficient reason for investigating the possibility of making improvements in the chemical composition of this important grain. The nature of any desired improvement will, of course, depend upon the use which is to be made of the crop produced. For example, if corn is grown for the manufacture of starch, glucose-sugar, sirup, or alcohol, it is desirable that the grain contain a high percentage of carbohydrates, and that the percentages of its other chief constituents, protein and fat, should be reduced as much as possible. If corn is used as feed for growing animals, or manufactured into corn flour for human food, a higher percentage of protein will certainly increase its value. If it is to be used chiefly for fattening stock, an increased percentage of fat might be the improvement to be desired. That the chemical composition of corn can be changed seems reasonably probable from the changes which have been produced in some other plants,—notably in the sugar-beet.

Before the work reported in this paper could be begun, it was found necessary to make a chemical study of the corn plant, and to devise methods for conducting experiments with the object of improving the composition of the grain. It is known that the mineral content of plants can be changed to some extent by the addition to the soil of mineral materials in a form readily available to the plant, but that the temporary change thus effected would have any appreciable hereditary tendency seems very unlikely. The method of procedure which seemed most promising is based upon the common method of making improvement in animals; namely, selecting the best examples of the desired type and breeding successively and under the best conditions from that stock, retaining from each generation only the highest types obtained. This is practically the method by which the

[1] Read before the American Chemical Society at the Columbus meeting held on August 21 and 22, 1899. This is an abstract from advance sheets of a bulletin on this subject, which will be published by the University of Illinois Agricultural Experiment Station as Bulletin No. 55, which will give the full data and details of these experiments.

sugar content of certain varieties of beets has been increased from less than five per cent. to twelve or even to sixteen per cent. A small portion of a beet is analyzed and, if it is found to be sufficiently rich in sugar, the beet is then set out, or planted, as a "mother," or seed, beet. From the seed produced beets are grown and another selection of seed beets is made on the basis of their sugar content. But the kernel of corn is not sufficient in quantity to make a complete chemical analysis by any practical method, and certainly the same kernel could not be used for analysis and also for seed.

Early in the year 1896 the writer began a special study of the chemistry of corn. Among the important facts indicated by the results obtained at that time were the following:

1. That the ear of corn is approximately uniform throughout in the composition of its kernels.

2. That there is a wide variation in the chemical composition of different ears of the same variety of corn.

That these conclusions are correct has been fully shown by some more recent work.[1] Approximate uniformity in the composition of the kernels, or grain, from the individual ear of corn has been established by the concordant evidence of a large number of analyses of parts of ears, and of many ash determinations and protein determinations in single kernels of corn. This may be illustrated by quoting the percentages of protein found in ten different kernels from each of two different ears:

| High-protein ear. | | Low-protein ear. | |
|---|---|---|---|
| Kernel No. | Protein. | Kernel No. | Protein. |
| 1 | 12.46 | 1 | 7.45 |
| 2 | 12.54 | 2 | 7.54 |
| 3 | 12.44 | 3 | 7.69 |
| 4 | 12.50 | 4 | 7.47 |
| 5 | 12.30 | 5 | 7.74 |
| 6 | 12.49 | 6 | 8.70 |
| 7 | 12.50 | 7 | 8.46 |
| 8 | 12.14 | 8 | 8.69 |
| 9 | 12.14 | 9 | 8.86 |
| 10 | 12.71 | 10 | 8.10 |

The following *highest* and *lowest* percentages of the more important constituents of the corn kernel, found in analyzing fifty different ears of a single variety of corn, may serve to illus-

[1] For complete data see University of Illinois Agricultural Experiment Station, Bulletin 53, 150–157 (1898).

trate the wide variation in the composition of corn from different ears :

| | Ash. | Protein. | Fat. | Carbohydrates. |
|---|---|---|---|---|
| Maximum..... | 1.74 | 13.88 | 6.02 | 85.79 |
| Minimum ..... | 1.09 | 8.35 | 3.95 | 78.92 |
| Difference | 0.65 | 5.53 | 2.07 | 6.87 |

With every constituent the variation is greater than Flechig[1] found with thirteen different varieties, and it is nearly as great as found by the Connecticut Experiment Station[2] with about seventy-five different varieties of corn grown under ninety presumably different conditions.

The uniformity of the individual ear of corn makes it possible to determine very approximately the composition of the grain by analyzing a sample consisting of a few rows of kernels from the ear. The remainder of the kernels of the ear may then be planted if desired. The wide variation in composition between different ears is a very important factor in the work of selecting seed, as a starting-point is thus furnished in each of the several lines of desired improvement.

The general plan[3] of the experiments to improve the chemical composition of corn was to make analyses of samples from a large number of ears, select for seed those ears which were found to contain a high percentage of the desired constituent, plant in an isolated field (to avoid cross fertilization from other corn), and grow the crop under as good field conditions as possible. From the crop obtained a large number of ears are selected, and samples of each ear are analyzed, seed being taken, as before, from those ears which are found to be highest in the percentage of the constituent which it is desired to increase. Each year this process is repeated. While it may require ten or twenty years' work to enable one to form a very definite opinion as to the extent to which it is possible to influence the chemical composition of corn, it is believed that the data and results thus far obtained may be of practical and scientific interest.

[1] Landwirtschaftliche Versuchs-Stationen, **32**, 17 (1886).

[2] Connecticut Agricultural Experiment Station, Annual Report (1893).

[3] All work reported in this paper was done upon a single variety of corn, commonly known as Burr's White. It has been grown for several years by the Illinois Agricultural Experiment Station with precautions to keep the variety pure and distinct. The analytical methods employed in the work herein reported have been described in detail in Bulletins 43 and 53 of the Illinois Station. All results are reported on the basis of dry matter, or water-free substance.

From the 1896 crop of Burr's White corn grown upon the Illinois Experiment Station farm, two bushels, or 163 ears, of good sound ear corn, suitable for seed, were selected. From each ear a sample consisting of three rows of kernels, lengthwise of the ear, was taken for analysis. From this lot of 163 ears, four different sets of seed corn were selected on the basis of chemical composition:

1. A set of twenty-four ears, each of which contained a high percentage of protein.

2. A set of twelve ears, whose percentage of protein was comparatively low.

3. A set of twenty-four ears, found to contain a high percentage of fat.

4. A set of twelve ears, containing a low percentage of fat.

Plans were made to carry on separately four direct experiments to change the chemical composition of corn; namely, (1) to increase the percentage of protein, (2) to decrease the protein, (3) to increase the fat, and (4) to decrease the fat. It is, of course, manifest that if the percentages of both protein and fat are increased, the percentage of carbohydrates must necessarily be decreased, and *vice versa*. By planting plots with both high-protein and low-protein corn, or with both high-fat and low-fat corn, results may be obtained which show the influence of selected seed, as independent and distinguishable from the effects due to the influence of the season.

In the spring of 1897 the four sets of corn which had been selected were planted on four different fields, or plots, each of which was fairly well isolated from other corn fields in order to avoid cross fertilization by corn of different chemical composition. For convenience these four plots are called: 1. High-protein plot; 2. Low-protein plot; 3. High-fat plot; 4. Low-fat plot. Invariably the seed planted in each row was all taken from a single ear; so that the high-protein plot, for example, contained twenty-four rows planted with seed from the twenty-four ears selected for that purpose. In the high-protein and high-fat plots the seed containing the very highest percentage of the desired constituent was planted in the middle rows, the remainder of the seed being planted in approximately uniform

gradation to either side. In the low-protein and low-fat plots the seed containing the very lowest percentages of protein and fat, respectively, was planted in the middle rows. This arrangement may be clearly seen by referring to the tables. The plots were given ordinary cultivation, and a good crop of corn was grown on each. When the corn was harvested a set of ten good ears was selected from each row, excepting from some outer rows. From some of the middle rows duplicate sets of ten ears each were taken from the same row, as will be seen from the tables, the analytical data from such rows being given in duplicate in all cases. Two rows of kernels (lengthwise of the ear) were taken from each of the ten ears and mixed to form a composite sample for analysis to represent the good corn grown on each row in the plots.

## EXPERIMENTS TO INFLUENCE THE PROTEIN IN CONTENT OF CORN.

The results from the experiments to change the percentage of protein in corn will be first considered. The following tables are arranged to show the percentage of protein in the dry matter of the seed planted and the crop produced in 1897. For reference, the laboratory serial numbers of all samples whose analyses are herein shown are also given.

TABLE 1.—PROTEIN IN CORN PLANTED AND HARVESTED ON HIGH-PROTEIN PLOT IN 1897.

| | Corn planted. | | Corn harvested. | |
|---|---|---|---|---|
| Plot row No. | Corn No. | Protein. Per cent. | | Protein. Per cent. |
| 1 | 94 | 11.89 | 270 | 9.61 |
| 2 | 86 | 12.07 | 275 | 11.07 |
| 3 | 230 | 12.10 | 280 | 10.94 |
| 4 | 213 | 12.40 | 285 | 11.48 |
| 5 | 100 | 12.28 | 290 | 10.85 |
| 6 | 119 | 12.38 | 295 | 11.64 |
| 7 | 227 | 12.63 | 300 | 11.46 |
| 8 | 153 | 12.51 | 305 | 11.57 |
| 9 | 175 | 12.68 | 310 | 11.17 |
| 10 | 84 | 12.79 | 315 | 11.14 |
| 11 | 110 | 12.81 | 320 | 11.16 |
| 12 | 126 | 13.87 | 325 | 11.60 |
| | | | 330 | 11.31 |
| 13 | 92 | 12.96 | 335 | 11.07 |
| | | | 340 | 11.44 |

| Plot row No. | Corn planted. Corn No. | Protein. Per cent. | Corn harvested. Corn No. | Protein. Per cent. |
|---|---|---|---|---|
| 14 | 177 | 13.06 | 345 | 10.89 |
| | | | 350 | 10.67 |
| 15 | 188 | 13.10 | 355 | 10.34 |
| | | | 360 | 11.48 |
| 16 | 232 | 12.76 | 365 | 11.05 |
| 17 | 87 | 12.40 | 370 | 10.75 |
| 18 | 204 | 12.57 | 375 | 10.86 |
| 19 | 105 | 12.36 | 380 | 11.07 |
| 20 | 141 | 12.42 | 385 | 10.88 |
| 21 | 172 | 12.28 | 390 | 11.73 |
| 22 | 222 | 12.34 | 395 | 10.76 |
| 23 | 147 | 12.21 | 400 | 11.30 |
| 24 | 208 | 12.05 | 405 | 11.53 |
| | Plot averages, | 12.54 | | 11.10 |

TABLE 2.—PROTEIN IN CORN PLANTED AND HARVESTED ON LOW-PROTEIN PLOT IN 1897.

| Plot row No. | Corn planted. Corn No. | Protein. Per cent. | Corn harvested. Corn No. | Protein. Per cent. |
|---|---|---|---|---|
| 1 | 151 | 9.31 | .... | .... |
| 2 | 114 | 9.12 | 410 | 10.55 |
| 3 | 83 | 9.08 | 415 | 10.89 |
| 4 | 225 | 9.15 | 420 | 10.26 |
| 5 | 116 | 8.38 | 425 | 10.10 |
| 6 | 145 | 8.25 | 430 | 10.73 |
| | | | 435 | 9.90 |
| 7 | 99 | 8.40 | 440 | 10.36 |
| | | | 445 | 10.20 |
| 8 | 215 | 9.22 | 450 | 9.89 |
| 9 | 185 | 9.33 | 455 | 10.24 |
| 10 | 164 | 9.36 | 460 | 11.20 |
| 11 | 113 | 9.30 | 465 | 12.24 |
| 12 | 193 | 9.47 | .... | .... |
| | Plot averages, | 9.03 | | 10.55 |

The average composition of the corn from the high-protein plot shows a protein content of 11.10 per cent., while 10.55 is the average percentage of protein in the corn from the low-protein plot, indicating that the difference, 0.55 per cent., may be ascribed to the influence of the seed selection. On account of the plan, or order, in which the seed corn was arranged in the plots, that is, with the corn of highest protein content in the central rows of the high-protein plot, and the corn of lowest pro-

tein content in the central rows of the low-protein plot, we might expect to find a somewhat wider average difference in protein content if we consider only the corn grown on the central half of each plot. From rows 7 to 18 of the high-protein plot we find the average protein content of the corn produced to be 11.12 per cent., while 10.21 is the average percentage of protein in the corn from rows 4 to 9 of the low-protein plot, thus showing an average difference of 0.91 per cent.

From each set of ten ears from the 1897 crop, four of those which appeared most suitable for seed corn were reserved for further use. From each of these ears a sample consisting of three or four rows of kernels was taken for analysis. In order to retain hereditary influences the seed for the high-protein plot for 1898 was all selected from corn which grew from seed of high-protein content the previous year. On this account corn with high-protein content from the low-protein plot was rejected for seed. Likewise seed for 1898 for the low-protein plot was selected only from corn which grew upon that plot in 1897.

In conducting the experiments in 1898 the same general plan of the previous year was followed, and the results obtained were nearly the same as in 1897, and the data obtained from the high-protein and low-protein plots will not be given in this paper.

In order to avoid local differences in the soil conditions, a third plot of ground was planted in 1898 with corn of known protein content. For want of a better name this is called the "mixed-protein plot." It contained five rows of ten hills each. In each hill were planted four kernels of corn of which two were high and two were low in protein content. The kernels were so arranged in the hill that the stalk of corn produced from each could be known. When the crop was harvested eight to ten ears from both the high-protein seed and the low-protein seed were taken from each row. By taking two rows of kernels from each ear ten composite samples were made, of which five represent the corn grown from the high-protein seed, in the five rows, and the other five represent the corn produced in the same rows from the low-protein seed. The following table shows the protein content of the seed planted and of the samples taken from the crop harvested.

TABLE 3.—PROTEIN IN CORN PLANTED AND HARVESTED ON MIXED-PROTEIN PLOT IN 1898.

| Plot row No. | Corn planted. Corn No. | Protein. Per cent. | Corn harvested. Corn No. | Protein. Per cent. | Corn planted. Corn No. | Protein. Per cent. | Corn harvested. Corn No. | Protein. Per cent. |
|---|---|---|---|---|---|---|---|---|
| 1 | 408 | 12.80 | 698 | 11.24 | 446 | 8.84 | 697 | 9.72 |
| 2 | 326 | 13.62 | 700 | 11.75 | 458 | 8.22 | 699 | 11.04 |
| 3 | 407 | 12.72 | 702 | 12.10 | 427 | 8.29 | 701 | 10.09 |
| 4 | 304 | 11.97 | 704 | 11.65 | 416 | 8.88 | 703 | 10.89 |
| 5 | 364 | 11.89 | 706 | 11.81 | 448 | 9.05 | 705 | 10.58 |
| | | Plot averages, | | 11.71 | | | | 10.46 |

The results of analysis show that in every row the high-protein seed produced corn with a higher protein content than that produced by the low-protein seed. The average protein content of the corn from the high protein seed is 11.71 per cent., while 10.46 is the average percentage of protein in the corn from the low-protein seed. This makes an average difference of 1.25 per cent. of protein which is attributable without question solely to the selection of seed on the chemical basis.

Incidentally it may be stated that the writer has found different ears of good sound Burr's White corn varying from 7.50 per cent. to 16.11 per cent. of protein in the dry matter. The fact that one good ear of corn with a protein content above 16 per cent. has been produced is a promise of the possibility of improving corn in that direction. Indeed, it is but reasonable to suppose that this limit may be reached again or even exceeded, and very possibly with corn in larger amounts than single ears.

Combined chemical and mechanical studies of the corn kernel have been reported by Salisbury,[1] Haberlandt and Lenz,[2] Atwater,[3], Voorhees,[4] and Balland.[5] The results obtained[6] show that the protein in the corn kernel is contained principally in the glutinous layer surrounding the main body of the kernel. This layer is very thin at the crown of the kernel but quite thick at the sides. The germ in the center of the tip end of the kernel is also rich in protein, although the entire germ constitutes

1 Trans. N. Y. State Agricultural Society, 8, 678 (1848).

2 *Allgemeine land- und fortswirtschaftliche Zeitung*, 257 (1866); Hoffmann; *Jsb. Agricultur-Chemie*, 9, 106 (1866).

3 Thesis, Yale College (1869); *American Journal of Science and Arts* [2], **48**, 352 (1869).

4 New Jersey Agricultural Experiment Station, Bulletin 105 (1894).

5 *Compt. rend.*, **122**, 1004 (1896).

6 University of Illinois Agricultural Experiment Station, Bulletin 53, 138-140 (1898).

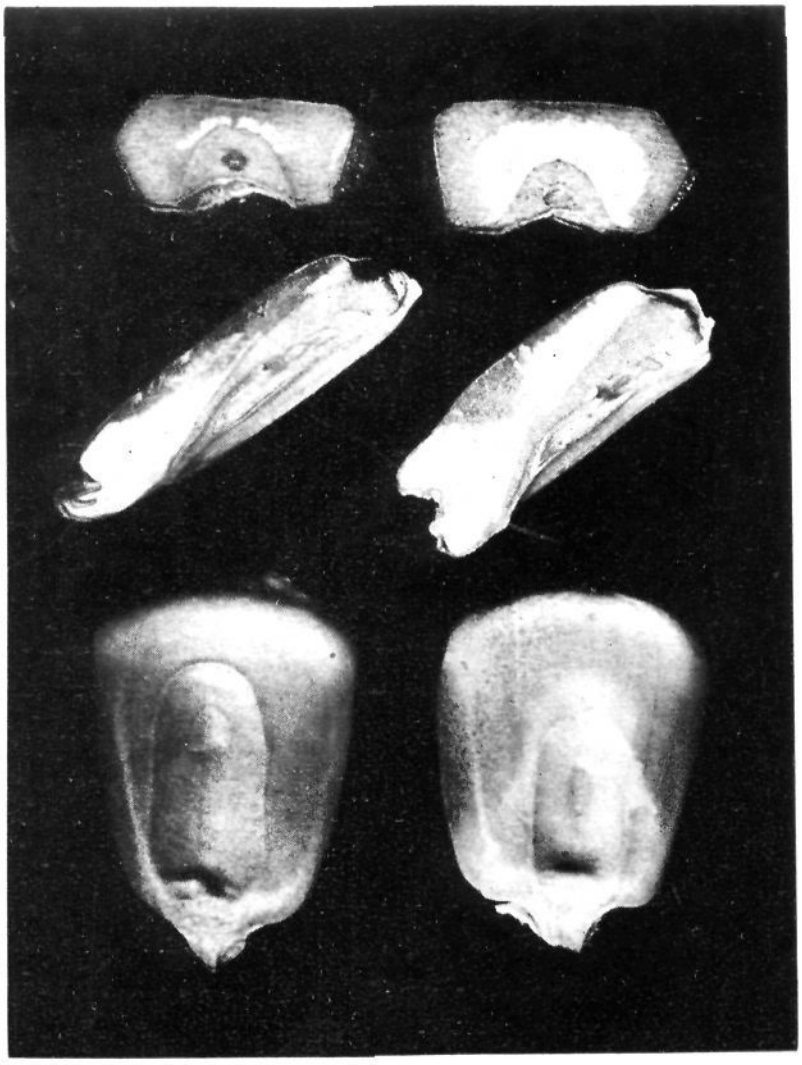

Fig. 1.

only about twelve per cent. of the kernel. The starchy portion, lying between the germ and the glutinous layer, consists almost entirely of carbohydrates, although the glutinous layer contains also a large percentage of carbohydrates.

On the basis of this knowledge of the general structure of the corn kernel and chemical composition of its several parts, the writer has made some investigations as to the possibility of selecting corn of high-protein content and of low-protein content by purely mechanical means, and has found that such a method is both possible and practicable. By making cross sections and longitudinal sections of several kernels from an ear of corn, one can judge with a very satisfactory degree of accuracy whether the corn is rich or poor in protein.

The illustration (Fig. 1) here shown was made from a photograph taken of the corn kernels and sections with a magnification of three diameters. At the left are two sections and a whole kernel from an ear of corn which contained 14.92 per cent. of protein. The sections and whole kernel at the right are from an ear containing 7.76 per cent. of protein. About one-fourth of the kernel was cut off from the tip end in making the cross sections. In the longitudinal sections the tip end of the kernel points upward to the right. It will be seen that in the cross sections the white, starchy layer nearly disappears in the high-protein corn but becomes very prominent in the low-protein corn. In the longitudinal sections this difference is also apparent, the white starch in the high-protein corn being confined almost entirely to the crown end of the kernel, while in the low-protein corn it extends into the tip in considerable amount. The germ in the high-protein corn is somewhat larger. This is also indicated by the size of the depressions in the whole kernels.

As an experiment about 300 ears of corn were examined by this mechanical method. Eighteen ears in the lot were picked out as possessing the physical characteristics which indicate a comparatively high content of protein, fifteen other ears which appeared to be low in protein being selected at the same time. Table 4 shows the results in detail, the percentage of protein in the corn from each ear being given as previously determined by chemical analysis.

TABLE 4.—ACTUAL PROTEIN CONTENT OF CORN SELECTED BY MECHANICAL EXAMINATION.

| Ear No. | Corn selected for High protein. Per cent. | Corn selected for Low protein. Per cent. |
|---|---|---|
| 1 | 11.47 | 11.48 |
| 2 | 12.04 | 9.06 |
| 3 | 9.69 | 9.90 |
| 4 | 11.78 | 9.15 |
| 5 | 11.65 | 9.67 |
| 6 | 11.38 | 10.11 |
| 7 | 11.64 | 9.11 |
| 8 | 11.22 | 10.25 |
| 9 | 11.97 | 8.63 |
| 10 | 11.94 | 9.63 |
| 11 | 10.96 | 8.61 |
| 12 | 10.83 | 10.95 |
| 13 | 11.87 | 11.27 |
| 14 | 10.21 | 9.36 |
| 15 | 11.71 | 10.25 |
| 16 | 11.59 | .... |
| 17 | 12.31 | .... |
| 18 | 10.54 | .... |
| Averages, | 11.38 | 9.83 |

The average protein content of the eighteen ears selected for high-protein corn is 11.38 per cent., while 9.83 is the average percentage of protein in the fifteen ears selected for low-protein corn. The examination consists in simply cutting cross sections and longitudinal sections from the kernels with a pocket-knife and judging as to the combined amount of glutinous layer and germ in relation to the quantity of white starchy matter, the observation being made with the naked eye. In making the selections the time given to each ear was about half a minute, and it is not assumed that the writer possesses any special skill in the art of judging the comparative sizes of small areas, or surfaces, the chief point involved in making these examinations. It seems but fair to suppose that the average corn-grower could, with some practice and care, make a better selection than is here shown. The selections shown in Table 4 were made from material[1] which was at hand and for the purpose of showing the

[1] NOTE.—The percentage of protein in the different ears in this plot of corn did not vary as much as would ordinarily be the case, because thirty-four of the ears highest in protein, and twenty-six of those lowest in protein, had previously been removed from this stock of corn, having been selected by chemical analysis.

feasibility of the method, rather than the extent to which it may be carried.

### EXPERIMENTS TO INFLUENCE THE FAT CONTENT OF CORN.

From the lot of 163 ears of corn from the 1896 crop, to which reference has already been made, seed was selected for the high-fat and low-fat plots for 1897. Good crops of corn were grown, and when harvested composite samples of corn from the different rows were taken and analyzed. The results obtained[1] indicate that the fat content of corn is influenced very markedly by selecting seed according to its percentage of fat. The difference between the average percentages of fat in the corn from the two plots is 0.67 per cent., the average from the high-fat plot being 4.73 and that from the low-fat plot 4.06 per cent. of fat. There is a difference of 0.79 per cent. of fat between the averages of the two crops if we consider only the central half of each plot. It is noteworthy that the lowest percentage of fat in the corn from any row of the high-fat plot is higher than the highest percentage obtained from any row in the low-fat plot.

From each set of ten ears from the 1897 crop four ears were taken for individual analysis, a sample of three or four rows of kernels (lengthwise of the ear) being taken from each ear for this purpose. For 1898 the seed for the high-fat plot was all from corn which grew from high-fat corn in 1897, twenty-four ears being selected. For the low-fat seed twelve ears were taken from the corn which grew from low-fat seed in 1897. The system of planting the highest of the high-fat seed and the lowest of the low-fat seed in the central rows of the respective plots was followed in 1898. Good crops of corn were grown, and when harvested sets of ten ears each were taken from each row, composite samples to represent each row being made, as before, by taking two rows of kernels from each of the ten ears. Tables 5 and 6 give the percentage of fat in the seed planted and in the crop produced, for each row of corn.

[1] The complete data are not given in this paper.

TABLE 5.—FAT IN CORN PLANTED AND HARVESTED ON HIGH-FAT PLOT IN 1898.

| Plot row No. | Corn planted. Corn No. | Fat. Per cent. | Corn harvested. Corn No. | Fat. Per cent. |
|---|---|---|---|---|
| 1 | 521 | 4.98 | 1240 | 4.86 |
| 2 | 533 | 4.98 | 1250 | 4.74 |
| 3 | 486 | 5.03 | 1260 | 4.94 |
| 4 | 531 | 5.04 | 1270 | 5.17 |
| 5 | 568 | 5.05 | 1280 | 5.36 |
| 6 | 528 | 5.12 | 1290 | 4.79 |
| 7 | 546 | 5.20 | 1300 | 4.87 |
| 8 | 534 | 5.27 | 1310 | 5.20 |
| 9 | 478 | 5.39 | 1320 | 5.16 |
| 10 | 511 | 5.44 | 1330 | 5.25 |
| 11 | 501 | 5.45 | 1240 | 5.21 |
| 12 | 524 | 5.68 | 1350 | 5.63 |
| 13 | 513 | 5.49 | 1360 | 5.21 |
| 14 | 512 | 5.45 | 1370 | 5.44 |
| 15 | 527 | 5.43 | 1380 | 5.48 |
| 16 | 514 | 5.39 | 1390 | 5.26 |
| 17 | 517 | 5.26 | 1400 | 5.55 |
| 18 | 559 | 5.12 | 1410 | 5.23 |
| 19 | 484 | 5.07 | 1420 | 5.06 |
| 20 | 544 | 5.02 | 1430 | 4.89 |
| 21 | 508 | 5.04 | 1440 | 5.00 |
| 22 | 547 | 5.00 | 1450 | 5.10 |
| 23 | 536 | 4.97 | 1460 | 5.05 |
| 24 | 494 | 4.97 | 1470 | 5.21 |
| | Plot averages, | 5.20 | | 5.15 |

TABLE 6.—FAT IN CORN PLANTED AND HARVESTED ON LOW-FAT PLOT IN 1898.

| Plot row No. | Corn planted. Corn No. | Fat. Per cent. | Corn harvested. Corn No. | Fat. Per cent. |
|---|---|---|---|---|
| 1 | 589 | 3.85 | 1480 | 3.97 |
| 2 | 574 | 3.83 | 1490 | 4.32 |
| 3 | 592 | 3.72 | 1500 | 4.08 |
| 4 | 602 | 3.55 | 1510 | 3.99 |
| 5 | 594 | 3.39 | 1520 | 3.81 |
| 6 | 614 | 3.39 | 1530 | 3.81 |
| 7 | 593 | 3.38 | 1540 | 3.69 |
| 8 | 606 | 3.50 | 1550 | 3.78 |
| 9 | 588 | 3.70 | 1560 | 3.93 |
| 10 | 603 | 3.80 | 1570 | 4.18 |
| 11 | 611 | 3.84 | 1580 | 4.21 |
| 12 | 591 | 3.85 | 1590 | 4.11 |
| | Plot averages, | 3.65 | | 3.99 |

The average fat content of the corn from the high-fat plot for 1898 is 5.15 per cent., while 3.99 is the average percentage of fat in the corn from the low-fat plot, making a difference of 1.16 per cent. between the averages. The difference becomes 1.45 per cent. if we consider only the central half of each plot, or 1.56 per cent. if only the central third of each plot is considered. Even the effect of planting the seed in gradation as to fat content from the center rows to either side is decidedly noticeable in the crop. It is only necessary to take averages of the fat content of the composite samples from the high-fat plot in groups of four to obtain a regular gradation in the same order as that of the seed. Thus:

| Corn. From rows. | Fat. Average per cent. |
|---|---|
| 1–4 | 4.93 |
| 5–8 | 5.06 |
| 9–12 | 5.31 |
| 13–16 | 5.35 |
| 17–20 | 5.18 |
| 21–24 | 5.09 |

In the low-fat plot the percentages of fat in the composite samples *from the single rows* are in regular gradation, if we omit only the outside rows, Nos. 1 and 12. This may be seen in Table 6.

In 1898 a third plot of ground for the study of the fat content of corn was planted. This is called the "mixed-fat plot," and was planted after the same plan as the mixed-protein plot. In each hill two kernels of high-fat corn were planted on one side and two of low-fat content on the other. The special object in this work was, of course, to avoid the influence of soil differences. From this mixed-fat plot twenty-seven pairs of ears were taken from twenty-seven hills, one ear in each pair having been grown from high-fat seed and the other ear from low-fat seed. Table 7 gives the fat content in the corn from each of these ears.

TABLE 7.—FAT IN CORN FROM FIFTY-FOUR EARS GROWN ON THE MIXED-FAT PLOT IN 1898.

| Hill No. | From high-fat seed. Corn No. | Fat. Per cent. | From low-fat seed. Corn No. | Fat. Per cent. |
|---|---|---|---|---|
| 1 | 762 | 4.05 | 761 | 3.82 |
| 2 | 764 | 4.42 | 763 | 3.62 |
| 3 | 766 | 4.65 | 765 | 3.03 |
| 4 | 768 | 4.90 | 767 | 3.92 |
| 5 | 770 | 5.16 | 769 | 3.94 |
| 6 | 772 | 5.06 | 771 | 3.99 |
| 7 | 774 | 5.13 | 773 | 4.15 |
| 8 | 776 | 4.95 | 775 | 3.75 |
| 9 | 778 | 5.59 | 777 | 3.60 |
| 10 | 780 | 4.10 | 779 | 4.04 |
| 11 | 782 | 4.49 | 781 | 3.56 |
| 12 | 784 | 5.25 | 783 | 4.26 |
| 13 | 786 | 5.65 | 785 | 4.15 |
| 14 | 788 | 5.03 | 787 | 4.08 |
| 15 | 790 | 5.57 | 789 | 3.57 |
| 16 | 792 | 5.32 | 791 | 4.69 |
| 17 | 794 | 5.75 | 793 | 3.96 |
| 18 | 796 | 4.95 | 795 | 4.64 |
| 19 | 798 | 4.79 | 797 | 4.30 |
| 20 | 800 | 4.59 | 799 | 4.33 |
| 21 | 802 | 5.56 | 801 | 3.77 |
| 22 | 804 | 5.34 | 803 | 4.17 |
| 23 | 806 | 4.92 | 805 | 4.50 |
| 24 | 808 | 5.91 | 807 | 3.58 |
| 25 | 810 | 5.86 | 809 | 4.55 |
| 26 | 812 | 4.59 | 811 | 3.96 |
| 27 | 814 | 5.02 | 813 | 4.23 |
| | Averages, | 5.06 | | 4.01 |

The average percentage of fat in the twenty-seven ears from the high-fat seed is 5.06, while 4.01 per cent. is the average fat content of the twenty-seven ears from the low-fat seed. It is interesting to note that in the twenty-seven hills there is no instance where the ear of corn from high-fat seed does not contain more fat than the ear grown from low-fat seed in the same hill.

The ear which grew from low-fat seed in hill No. 3 has the lowest fat content, 3.03 per cent., of any ear of corn which has been analyzed in these experiments. The maximum fat con-

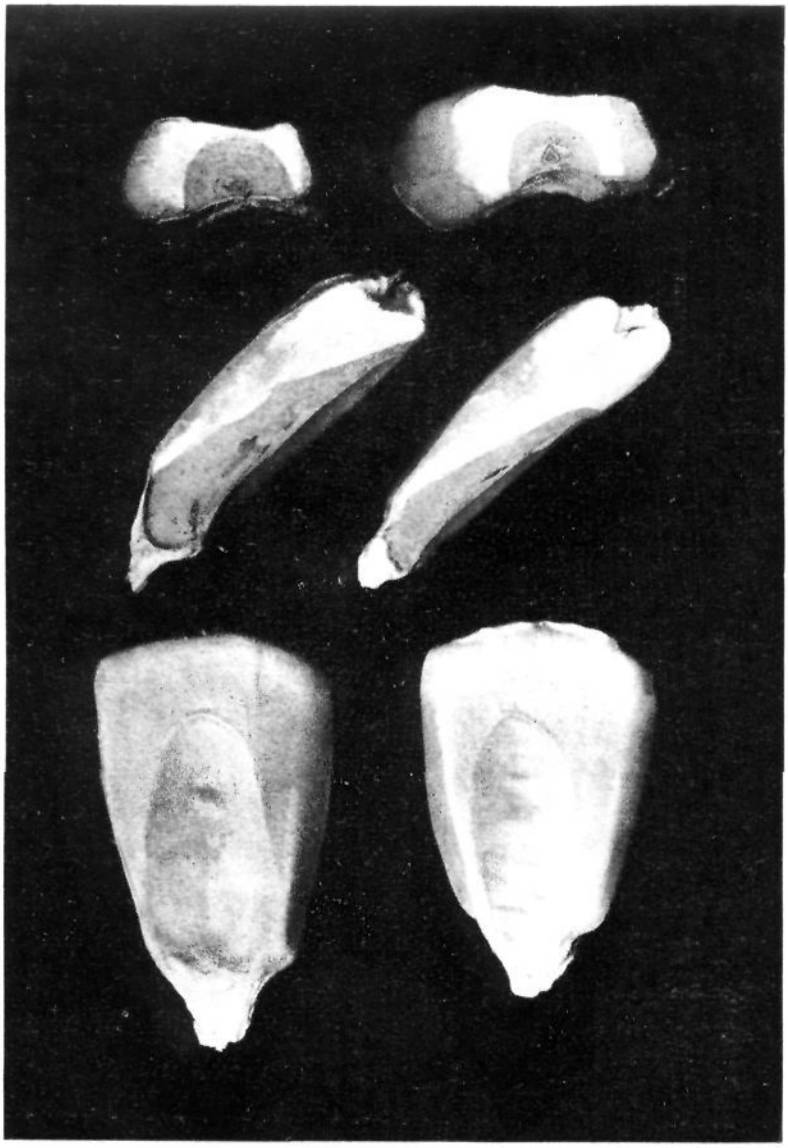

Fig. 2.

tent which has been found in an ear of Burr's White corn up to the present time is 6.71 per cent.

The fact that the fat, or oil, of the corn kernel is contained almost entirely in the germ[1] suggested to the writer the possibility of selecting corn of either high- or low-fat content by mechanical examination of the kernel and judging as to the quantity of germ compared with the remainder of the kernel. It was found that the method is possible and rather more satisfactory than the method (already described) of judging the protein content of the corn kernel by mechanical examination, as it is less complicated than the latter.

Figure 2 (made from a photograph taken with a magnification of three diameters) illustrates the difference in corn kernels of about the same size but a very different fat content. The cross sections shown at the top were made by cutting off about one-fifth of the kernel from the tip end. In the longitudinal sections the tip end of the kernel points downward to the left. The sections and whole kernel shown at the left are from an ear of corn which contains 6.08 per cent. of fat. Those at the right are from an ear containing 3.64 per cent. of fat. It will be seen that the germ is larger in the high-fat corn and that it extends nearly the entire length of the kernel, while in the low-fat corn the germ is small and only about two-thirds as long as the kernel.

To obtain exact data as to the relation between the percentage of fat and the percentage of germ in the corn kernel, the germs were removed[2] from a large number of kernels, the weight of the whole kernel and also of the separated germ being determined, and reported on the basis of dry matter, having been dried in hydrogen before being weighed. Table 8 will serve to illustrate the results obtained in this work.

[1] See University of Illinois Agricultural Experiment Station, Bulletin 53, 139, 140 (1898).

[2] It was found that after soaking corn kernels in hot water for about thirty minutes the germs are easily removed in the entire state and quite free from other portions of the kernel.

TABLE 8.—WEIGHT OF CORN KERNELS WITH WEIGHT AND PERCENTAGE OF GERMS.

| Corn No. 1352—Fat = 6.71 per cent. | | | | Corn No. 1529—Fat = 3.22 per cent. | | | |
|---|---|---|---|---|---|---|---|
| Kernel No. | Kernel weight. Gram. | Germ weight. Gram. | Germ. Per cent. | Kernel No. | Kernel weight. Gram. | Germ weight. Gram. | Germ. Per cent. |
| 1 | 0.3113 | 0.0391 | 12.56 | 1 | 0.2859 | 0.0250 | 8.74 |
| 2 | 0.2872 | 0.0360 | 12.53 | 2 | 0.2882 | 0 0237 | 8.22 |
| 3 | 0.2864 | 0.0340 | 11.87 | 3 | 0.3533 | 0.0297 | 8.41 |
| 4 | 0.2821 | 0.0374 | 13.26 | 4 | 0.3135 | 0.0265 | 8.45 |
| 5 | 0.2667 | 0.0360 | 13.50 | 5 | 0.3277 | 0.0273 | 8.33 |
| 6 | 0.3694 | 0.0442 | 11.97 | 6 | 0.3417 | 0.0310 | 9.07 |
| 7 | 0.3434 | 0.0414 | 12.06 | 7 | 0.2918 | 0.0257 | 8.81 |
| 8 | 0.2682 | 0.0300 | 11.18 | 8 | 0.3178 | 0.0276 | 8.68 |
| 9 | 0.3116 | 0.0402 | 12.90 | 9 | 0.3273 | 0.0278 | 8.49 |
| 10 | 0.2870 | 0.0348 | 12.13 | 10 | 0.3338 | 0.0280 | 8.39 |
| Av'ges, | 0.3013 | 0.0373 | 12.40 | Averages, | 0.3181 | 0.0272 | 8.56 |

In corn No. 1352, containing 6.71 per cent. of fat, and corn No. 1529, containing 3.22 per cent. of fat, the kernels are approximately uniform in size, the former being 0.3013 and the latter 0.3181 gram in average weight; but the germs in the high-fat ear amount to 12.40 per cent. of the whole kernels, and to only 8.56 per cent. in the low-fat ear. This difference in percentage is due to the absolute difference in the size of the germs, the germs from the high-fat kernels being 0.0373 gram and from the low-fat kernels only 0.0272 gram average weight.

From a large amount of data the general relation between the percentage of fat and the percentage of germ in the corn kernel has been clearly established. Of course there are minor individual differences among the kernels from the same ear, and it has also been noted that there is a difference in different ears as to the relation between fat content and germ content. These minor differences are perhaps due in part to the varying percentage of fat in the body of the kernel, but the variation in the percentage of fat in the germs, especially from different ears, is doubtless the chief factor in producing such differences. For example, Voorhees[1] found 26.65 per cent. of fat in the germs of the corn kernel, while Balland[2] found 39.85 per cent.

The method of selecting corn of high- or low-fat content by mechanical examination is similar to that described under the work on the protein content of corn, excepting that the size of

[1] New Jersey Agricultural Experiment Station, Bulletin 105 (1894).

[2] *Compt. rend.*, **122**, 1004 (1896).

the germ alone as compared with the remainder of the kernel is considered. Judgment is formed by examining with the naked eye the cross sections and longitudinal sections of a few kernels from each ear. To make a practical test of the method nearly 300 ears of corn were examined, which varied in fat content[1] from about 3.60 to 5.80 per cent. From this lot of corn, by mechanical examination, eighteen ears were selected which appeared to possess a comparatively high-fat content, and at the same time thirty ears apparently low in fat were picked out. Tables 9 and 10 show the results in detail, the percentage of fat in the corn from each ear being given as previously determined by chemical analysis.

TABLE 9.—FAT CONTENT OF EIGHTEEN EARS SELECTED BY MECHANICAL EXAMINATION FOR HIGH-FAT CORN.

| Ear No. | Fat. Per cent. | Ear No. | Fat. Per cent. |
|---|---|---|---|
| 1 | 4.94 | 10 | 5.33 |
| 2 | 4.30 | 11 | 5.55 |
| 3 | 5.43 | 12 | 4.99 |
| 4 | 5.64 | 13 | 5.27 |
| 5 | 5.23 | 14 | 5.12 |
| 6 | 5.58 | 15 | 5.73 |
| 7 | 5.06 | 16 | 5.43 |
| 8 | 5.26 | 17 | 4.97 |
| 9 | 5.22 | 18 | 5.21 |
| | | Average, | 5.24 |

TABLE 10.—FAT CONTENT OF THIRTY EARS SELECTED BY MECHANICAL EXAMINATION FOR LOW-FAT CORN.

| Ear No. | Fat. Per cent. | Ear No. | Fat. Per cent. |
|---|---|---|---|
| 1 | 4.01 | 16 | 3.63 |
| 2 | 4.11 | 17 | 4.02 |
| 3 | 3.64 | 18 | 4.55 |
| 4 | 3.67 | 19 | 4.52 |
| 5 | 4.52 | 20 | 4.29 |
| 6 | 3.66 | 21 | 3.81 |
| 7 | 4.07 | 22 | 4.39 |
| 8 | 4.20 | 23 | 4.43 |
| 9 | 3.91 | 24 | 3.80 |
| 10 | 4.85 | 25 | 4.09 |
| 11 | 4.35 | 26 | 4.27 |
| 12 | 4.52 | 27 | 4.02 |
| 13 | 3.73 | 28 | 3.87 |
| 14 | 3.76 | 29 | 4.00 |
| 15 | 5.21 | 30 | 3.98 |
| | | Average, | 4.13 |

[1] Twelve ears of corn of very high fat content and sixteen ears of very low fat content had been previously taken from this lot and used for seed in 1899, otherwise the results would no doubt have been even more marked than they are.

The average fat content of the ears selected for high-fat corn is 5.24 per cent., while 4.13 is the average of that selected for low-fat corn. If we omit a single ear from each set, the lowest percentage of fat in the ears selected for high-fat content is higher than the highest percentage of fat in the low-fat selection.

## SUMMARY AND DEDUCTIONS.

All results thus far obtained from our experiments indicate that it is not only possible but entirely practicable to influence the chemical composition of corn, that by proper selection of seed any of its principal constituents, protein, fat, or carbohydrates, may be increased or decreased.

In every experiment the selection of seed corn of high- and of low-protein content has produced marked effects in the crop, differences varying from 0.50 to 1.25 per cent. of protein; and in the experiments to influence the fat content of corn, the selection of seed of high- and of low-fat content has produced differences in the crops varying from 0.67 to 1.45 per cent. of fat.

Considering the fact that the average fat content of Burr's White corn is less than five per cent., the proportion of fat in corn is much more susceptible to the influence of seed selection than is the protein content. This is doubtless due to the fact that the primary materials from which fat is manufactured, namely, carbon dioxide and water, are usually furnished to the plant in unlimited supply, while the formation of protein is essentially dependent upon the supply of available nitrogen in the soil.

As the percentage of carbohydrates (principally starch in corn) varies inversely with the combined percentages of protein and fat (neglecting the small percentage of ash found in corn), it follows that the carbohydrates are increased in percentage whenever the combined percentage of protein and fat is decreased, and *vice versa*.

By actual trial it has been found both possible and practicable to select corn by mechanical examination with either high or low content of protein, fat, or starch.

While further investigations are necessary and are in progress to determine more accurately the best methods and more definitely the possibilities of improvement in the chemical composition of corn, it is here stated, tentatively, that essentially by the

methods reported in this paper any corn-grower will be able to select seed and to breed corn to increase or to decrease the percentage of any of its three principal chemical constituents.

All experiments reported in this paper have been carried on with the one variety of corn, namely, Burr's White. Of course it is not believed that Burr's White is the very best variety for improvement in corn in every one of the several important lines. Indeed, it seems highly probable that one variety of corn will be found best adapted to but one line of improvement. We have in progress chemical studies of other varieties of corn, and a considerable amount of data and information has been already acquired, but it is reserved, pending further investigations for future publication, the special object of this article being to give some of the data, thus far obtained, indicating the possibility and establishing the fact that the corn kernel may be improved in chemical composition.

It may be stated that improvement in the composition of other parts of the corn plant is under consideration by the Illinois Station. Plans are also made to investigate other questions relating to this general subject; such as the effect of changes in the chemical composition of corn upon its digestibility, vitality, yield, etc.

The results obtained in our investigations to improve the composition of corn have suggested the possibility of improving other grains by somewhat similar methods. It seems not improbable that the different grains, or kernels, produced in a single head of wheat, oats, or barley, may be found to be approximately uniform in composition.[1] If so, a method is thus afforded for selecting seed and breeding those cereals upon the basis of the chemical composition of the grain.

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## NOTE.

*The Determination of Chromium in Steel.*—A method for the determination of chromium in steel, based upon its oxidation to chromic acid by potassium chlorate in nitric acid, and the titration of the chromic acid with ferrous sulphate and potassium

[1] Since this was written a chemical study of wheat has been begun in this laboratory, and in general the results thus far obtained support the suggestion which is offered above.