1930

# Composition and structure of the cornstalk as related to its industrial utilization

Florence Everett Hooper
*Iowa State College*

# COMPOSITION AND STRUCTURE OF THE CORNSTALK AS RELATED TO ITS INDUSTRIAL UTILIZATION

BY

Florence Everett Hooper

A Thesis submitted to the Graduate Faculty
for the Degree of

DOCTOR OF PHILOSOPHY

Major subject - Plant Chemistry

Approved

Signature was redacted for privacy.
In charge of Major work

Signature was redacted for privacy.
Head of Major Department

Signature was redacted for privacy.
Dean of Graduate College

Iowa State College

1930

UMI Number: DP14464



ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

# TABLE OF CONTENTS


| | Page |
|---|---|
| ACKNOWLEDGMENTS | 4 |
| INTRODUCTION | 5 |
| DESCRIPTIVE AND HISTORICAL | 6 |
| EXPERIMENTAL | |
| A. Analyses and Specific Gravity Measurements for Several Parenchymatous and Vascular Tissues | 12 |
| Method | 12 |
| Preparation of tissues | 12 |
| Specific gravity measurements | 14 |
| Analyses | 16 |
| Results | 17 |
| B. Study of Acetylated Parenchymatous and Vascular Tissues of the Cornstalk | 28 |
| Method | 28 |
| Results | 30 |
| C. Study of the Location of the Cell Wall Constituents of Parenchymatous and Vascular Tissues of the Mature Cornstalk | 33 |
| Method and Results | 34 |
| D. Microscopic Study of Cellulose Pulps Prepared from Parenchymatous and Vascular Tissues of the Cornstalk | 43 |
| Method and Results | 43 |
| Measurement of the cells of the pulps | 43 |
| Disintegration of the cells of the pulps by phosphoric acid-absolute alcohol treatment | 45 |

Page

E. Microscopic Study of Several Wallboards . . . . . 52

Methods and Results . . . . . 53

GENERAL DISCUSSION . . . . . 68

SUMMARY . . . . . 72

LITERATURE CITED . . . . . 73

## ACKNOWLEDGMENTS

The author wishes to express her sincere appreciation to Dr. R. M. Hixon for his assistance and encouragement during the course of this investigation, and to Dr. J. N. Martin for his assistance in the botanical phases of the work.

# INTRODUCTION

Recent work on the industrial utilization of agricultural wastes has included a study of methods available for the possible utilization of cornstalks (16). Such material differs from wood, which consists mainly of xylem, in the presence of an appreciable amount of parenchyma. Most of the weight of the mature stalk is due to cell wall material. The marked difference in properties exhibited by the parenchymatous and vascular tissues of the mature cornstalk indicates that it may be desirable to utilize these tissues for different purposes or to subject them to different treatments. The selection of the most efficient method for the utilization of these tissues will depend on a more complete knowledge of them. In view of these facts, a comparison of the cell wall materials of parenchymatous and vascular tissues is of practical as well as of botanical interest.

## DESCRIPTIVE AND HISTORICAL

The term, cornstalk, is used to denote the stem of the annual herbaceous grass, Zea Mays, dent variety. The stem consists of a solid cylinder of pith traversed longitudinally by scattered vascular bundles. The bundles become increasingly numerous toward the periphery, the outermost ones forming a compact woody shell, varying in thickness from about one-fourth inch at the base of the stalk to about one-sixteenth inch at the top. The outer part of the shell is covered by a single layer of epidermal cells. The bundles branch and anastomose at the nodes, thus forming a dense region consisting almost entirely of vascular tissue. Wiley (24) found that the nodes constitute about 26% of the weight of the stalk, the shell of the internodes about 54%, and the pith with its included vascular bundles about 20%. Examination of a number of these pithy cylinders from typical internodes indicated that about 60 -70% of the cylinder or about 13% of the total stalk consists of fundamental parenchyma. One of the chief objections which has been raised to the stalk as a utilizable waste is the presence of such structurally dissimilar tissues.

If the epidermal layer is disregarded, the entire stalk may be said to consist of parenchymatous and vascular tissue. The pith or fundamental parenchyma is a simple tissue, composed of large, isodiametric, thin walled cells. The vascular material, on the other hand, includes two complex tissues,

phloem and xylem, and two simple tissues, sclerenchyma and parenchyma. The sclerenchyma, which consists of heavy walled, cylindrical cells with diameters many times less than the diameter of the average pith cell, is structurally similar to the tracheids, the most abundant of the xylem cells. For this reason, the term xylem will be used to include all cells of this type. Since the parenchyma and phloem constitute only a small part of the total weight of the vascular tissue, the properties of this material may be regarded as essentially due to xylem.

According to the generally accepted view, the cell walls of parenchyma and xylem of a given plant are chemically different. This conception is based on the results of microchemical tests and staining reactions. Although no work of this type on the tissues of the cornstalk has been reported in the literature, these tissues are frequently used in histology courses to demonstrate the use of such tests. Furthermore, such a conception seems to be in accord with the marked difference in properties exhibited by the pith and vascular material. For example, the soft and easily compressible pith has a lesser apparent specific gravity than the woody vascular tissue and is more readily subject to biological and chemical attack. Microchemical and staining methods have the disadvantage of being entirely non quantitative. Furthermore, recent work has questioned the reliability of such methods (page 33).

Various macrochemical methods have been developed for the estimation of cell wall constituents. Most of these methods are based on the assumption that certain reaction solvents, such as acids, alkalies, etc., have a selective action on the constituents of the wall. Actually, it seems unlikely that these reagents either entirely remove or leave a residue consisting of any one constituent. Furthermore, the treatment with such solvents is probably in many cases sufficiently drastic to induce chemical changes in the wall constituents. In this case, the product estimated as a wall constituent is in reality a reaction product of one or more of these constituents. The purely arbitrary character of such procedures is evidenced by the fact that the various methods for the estimation of any one constituent seldom give identical results. Other methods are based on the estimation of some characteristic group, as for example, the determination of pentosans as furfural phloroglucide (2). In view of the fact that the exact relation of such groups to the molecule of the constituent is usually unknown, such methods are also open to criticism. Although the proposed macrochemical methods are open to these criticisms, they offer one of the most satisfactory methods at present available for the examination of plant materials.

By the use of such methods, Peterson and Hixon (17) analyzed hand separated parenchyma and vascular fractions of the mature cornstalk for the wall constituents known to be

present, namely: lignins, pentosans, and cellulose. The analytical results for the two separated tissues and for the total stalk were practically the same (table I). Wiley (24) had previously obtained analytical results on such fractions which were also more nearly in agreement than would be expected from the previously mentioned conception of cell wall chemistry (table II). Wiley (24) and Burke (3) reported similar results for the pith and woody fractions of the corncob, a modified stem structure (tables III and IV). Such results suggest that the cell walls of parenchyma and vascular material are more nearly alike chemically than has been supposed. Additional evidence for or against the hypothesis that these tissues are chemically similar should be obtained from a comparative study of parenchyma and vascular material.

Table I

Analytical Data for Parenchymatous and Vascular Fractions of the Mature Cornstalk as Determined by Peterson and Hixon (17).

| % | Vascular Tissue: Shell | Vascular Tissue: Bundles | Parenchyma | Total Stalk |
|---|---|---|---|---|
| Pentosan | 25.9 | 26.4 | 27.7 | 27.6 |
| Lignin | 33.5 | 35.2 | 32.0 | 34.3 |
| Cellulose pulp | 55.9 | 50.2 | 50.1 | 52.6 |
| Pentosan in pulp | 16.6 | 13.1 | 12.2 | 14.2 |
| Cellulose (by difference) | 39.3 | 37.1 | 37.9 | 38.4 |

Table II

Analytical Data for Parenchymatous and Vascular Fractions of the Mature Cornstalk as Determined by Wiley (24).

| % | Vascular Tissue: Shell | Vascular Tissue: Nodes | Parenchymatous Tissue: Pith and Inner vascular bundles |
|---|---|---|---|
| Cellulose | 53.44 | 50.96 | 51.57 |
| α-Cellulose | 40.35 | 35.12 | 33.07 |
| Xylan | 20.60 | 22.53 | 21.29 |
| Soluble in 1.25% $H_2SO_4$ at 3 atmos. for 30 minutes. | 37.69 | 44.28 | 54.27 |
| Soluble in 1% NaOH at 1 atmos. for 30 minutes | 43.12 | 44.28 | 45.74 |
| Soluble in 1% NaOH at 3 atmos. for 30 minutes | 48.03 | 51.45 | 53.11 |

Table III

Analytical Data for Parenchymatous and Vascular Fractions of the Mature Corncob as Determined by Wiley (24).

| % | Vascular Tissue* | Parenchyma |
|---|---|---|
| | Shell | Pith |
| Moisture | 9.08 | 8.11 |
| Ether extract | 0.23 | 0.52 |
| Fiber | 32.17 | 34.15 |
| Ash | 1.55 | 2.43 |
| Protein | 1.75 | 2.06 |

*These values probably include the shell and the chaff.

Table IV

Analytical Data for Parenchymatous and Vascular Fractions of the Mature Corncob as Determined by Burke (3).

| % | Vascular Tissue | Parenchyma |
|---|---|---|
| Crude fiber | 27.30 | 35.85 |
| Starch | 34.45 | 30.29 |
| Pentosans** | 39.54 | 34.54 |

**These values are averages of the values obtained from three fractions of material of slightly different age.

# EXPERIMENTAL

## A. Analyses and Specific Gravity Measurements for Several Parenchymatous and Vascular Tissues.

Analytical data of the type obtained by Peterson and Hixon (17) gives no information concerning the nature of the association of the constituents in the cell wall. It is possible that the same substances may be present in the same proportion by weight, and yet be so associated as to produce a chemical difference in the walls. Since chemically different substances are characterized by a difference in physical constants, the desirability of supplementing the analytical data with measurements of such constants is apparent. For this reason, analyses and specific gravity measurements were made on parenchyma and vascular material from the stems of the following plants: (a) ordinary field corn (Zea Mays), (b) and (c) two genetically pure strains of corn (Zea Mays),* differing only with respect to the gene controlling rigidity, one being weak and prostrate, the other strong and erect, (d) sugar cane (Saccharum officiarum), (e) sorghum cane (Sorghum vulgare), and (f) Jerusalem artichoke (Helianthus tuberosus).

### Method

#### Preparation of the tissues.

The preliminary treatment of the plant materials consisted

*These tissues were kindly supplied by Dr. Fisk Gerhardt of the Chemistry Section of the Iowa Agricultural Experiment Station, Ames, Iowa.

of separation into different tissues or combinations of tissues, grinding, and extraction with such solvents as were expected to leave a residue consisting of relatively pure, unchanged cell wall material. Internodes of stems of the first five plants named above were separated, by peeling with a sharp knife, into two portions: (a) the outer shell of the stalk, consisting of the epidermis and the peripheral vascular bundles, and (b) the central cylinder of the stalk, consisting of the inner vascular bundles and the pith or fundamental parenchyma. The separation of the sugar cane into shell and central cylinder was immediately followed by extraction with acetone to reduce the sugar concentration to such a point that the tissue could be dried by evaporation in air. The central cylinders of the field corn and sugar cane were further separated into vascular bundles and pith. This was accomplished by carefully pulling out the bundles from cylinders which had been softened by soaking and boiling in water. The Jerusalem artichoke stem was split lengthwise and the inner cylinder of purely parenchymatous tissue was scraped out.

Unless otherwise indicated, all tissues were ground to pass a 60 mesh screen. Extraneous materials were removed by exhaustive extraction with water and alcohol. The tissues were air dried before extraction with a new solvent. The final alcoholic extractions of sorghum and artichoke tissues were carried out in Soxhlets. This seemed necessary to remove the

large amount of coloring matter present in these tissues. All specific gravity measurements and analyses were made on air dried tissues.

Specific gravity measurements.

Specific gravity measurements were made by displacement of alcohol. The specific gravity values were calculated from the following formula:

$$\frac{S \times D_1}{(A_1 - A)} = D$$

where $A_1$ is the weight of alcohol held by the pyknometer when no sample is present, A the weight of alcohol held when the sample, S, is present, $D_1$ the specific gravity of the alcohol, and D the specific gravity of the tissue.

A 100 cc. pyknometer fitted with a ground glass stopper with a capillary outlet was used. The pyknometer was calibrated to the fourth decimal place at the temperature at which the measurements were to be made. For all measurements, the pyknometer was completely filled with liquid and was brought to constant temperature, by immersing up to its neck for thirty minutes in a water thermostat where the maximum temperature variation was not over $0.02^{\circ}C$. The pyknometer was suspended in the thermostat in a small cylindrical basket of copper gauze in which it was held in an upright position by two adjustable copper wires drawn across the top of the basket. This method necessitated less handling of the

pyknometer than would the use of a clamp. Furthermore, the basket allowed free circulation of the water and yet served to protect the surface of the pyknometer from most of the lint and scum which were always present in the thermostat. The joint of the pyknometer was protected from any alcohol which might overflow from the capillary outlet, by placing a tight fitting collar of filter paper around the stopper above the joint. Before weighing, the surface of the pyknometer was dried and cleaned by wiping with a cloth moistened with alcohol and ether. The samples of tissue used were of such size that in the dry condition a sample filled one-fourth to one-third the volume of the pyknometer. Samples of greater size interfered with subsequent manipulations. The sample was well covered with alcohol of known specific gravity, at least twenty-four hours before the measurement was to be recorded, to allow for penetration of the tissue. After penetration had occurred, as evidenced by the appearance and the sinking of the tissue, the pyknometer was carefully rotated in such a way that its entire contents were seen in motion. This was necessary to remove air bubbles which lodged in the mass of tissue. Check readings were obtained several times on each sample by bringing to constant temperature, readjusting the alcohol level, and weighing. The contents of the pyknometer were agitated between readings to make certain that all the air had been removed.

An interesting observation was made in the use of the

pyknometer. When the joint was reground, the stopper was pushed into the neck of the pyknometer to such an extent that a small groove was formed at the top of the joint, where the diameter of the neck of the pyknometer was greater than that of the stopper. When an attempt to dry the surface of the filled pyknometer was made, it was noted that more liquid immediately took the place of any that was removed from this groove. When the groove was removed by grinding down the neck of the pyknometer until a right angle point of contact between stopper and pyknometer was obtained, no more difficulty was encountered in drying or weighing the pyknometer. Apparently the layer of liquid which was always present in the groove after filling the pyknometer exerted such a pull on the liquid held between the stopper and pyknometer that a constant capillary rise occurred along this joint.

Analyses.

No attempt to make a complete analysis of the various tissues was made. Moisture, pentosans, lignins, and, if the supply of material permitted, cellulose analyses were made on all tissues. The lignin analyses were obtained by the 72% sulphuric acid method, using the procedure recommended by Schorger (22). Pentosans were determined as furfural phloroglucide (2). The cellulose pulp was prepared by a modification of the de Vain's process. The pentosan content of the pulp was determined and calculated to percent of original

stalk. By subtracting this figure from the percent of original stalk obtained as pulp, a value for cellulose by difference was obtained.

## Results

The experimental data are shown in table V. The values given for specific gravity are averages of values obtained on two or more samples of tissue. The value for each sample is in turn an average of at least two and more often three or more readings on that sample. The specific gravity values and the data from which they were calculated are given in tables VI - XI. The analytical values are averages of two or three determinations.

The specific gravity, pentosan, and cellulose values for the parenchymatous fraction are approximately equal to the corresponding values for the vascular fraction in ordinary field corn, the two genetically pure strains of corn, sorghum cane, and sugar cane. The lignin content of the two fractions were also found to be the same in those tissues where the lignin determinations were run at room temperature, namely: those of field corn, the two genetically pure strains of corn, and sorghum cane. Peterson (16) recently reported that a difference in lignin content was found in the two tissues of the cornstalk when the analyses were run at the temperature of the ice box. Since his values by this method checked those

Table V

Specific Gravity and Composition of Parenchyma and Vascular Cell Wall Material.

(Analytical results calculated to percentage of oven-dry (105°C.) samples).

| Plant | Tissue | Specific gravity at 25°C. | % Lignins | % Pentosans | % Cellulose in pulp | % Pentosans in pulp | % Cellulose by difference |
|---|---|---|---|---|---|---|---|
| Corn[a] | Pith[d] | 1.52[f] | 32.0<br>16.5[h] | 27.7 | 50.1 | 12.2 | 37.9 |
| | Inner vascular bundles[e] | 1.515[f] | 35.2<br>22.5[h] | 26.4 | 50.2 | 13.1 | 37.1 |
| | Shell | 1.52[f] | 33.5<br>25.2[h] | 25.9 | 55.9 | 16.6 | 39.3 |
| Corn, genetic strain 201, weak[b] | Central cylinder | 1.515 | —[g] | 28.8 | | | |
| | Shell | 1.515 | 23.1 | 27.2 | | | |
| Corn, genetic strain 201, strong[b] | Central cylinder | 1.51 | —[g] | 29.5 | | | |
| | Shell | 1.52 | 24.65 | 29.3 | | | |
| Sugar cane[c] | Pith[d] | 1.50 | 18.4[h] | 32.4 | | | |
| | Inner vascular bundles | 1.49 | | | | | |
| | Shell | 1.52 | 25.4[h] | 30.7 | | | |
| Sorghum cane | Central cylinder | 1.503 | 21.7 | 31.1 | | | |
| | Shell | 1.502 | 23.0 | 33.4 | | | |
| Jerusalem artichoke | Pith | 1.540 | 10.1 | 25.6 | 48.5 | 5.6 | 42.9 |
| | Shell | 1.406 | 23.9 | 22.6 | 53.2 | 11.4 | 41.8 |

[a]The analytical data for corn is that listed by Peterson and Hixon (17).

[b]This tissue and the analyses for pentosans on it were kindly supplied by Dr. Fisk Gerhardt of the Chemistry Section of the Iowa Agricultural Experiment Station, Ames, Iowa.

[c]This tissue was kindly supplied by the Louisiana Sugar Experiment Station, Baton Rouge, Louisiana.

[d]This tissue could not be ground to pass a 60 mesh screen in the mill used. When the tissue reached its maximum state of fineness it was removed from the upper part of the mill and used without further subdivision.

[e]The vascular bundles were cut into 1/16 to 1/4 inch lengths with the scissors and were not ground in the mill.

[f]This value was determined at 29°C.

[g]An insufficient supply of this tissue prevented the determination of its lignin content.

[h]This analysis was run at the temperature of the ice box.

Table VI

Specific Gravity of Parenchymatous and Vascular Fractions of the Mature Cornstalk.

| Tissue | S = Weight of sample: | $D_1$ = Specific gravity of alcohol. | $(A_1-A)$ = Weight of alcohol displaced by sample: | $D=\frac{S \times D_1}{(A_1-A)}$ | Average specific gravity of each sample. | Average specific gravity of each tissue. |
|---|---|---|---|---|---|---|
| Pith | 0.5495 | 0.8034 | 0.2925 | 1.51 | 1.52 | 1.52 |
| | 0.5495 | 0.8034 | 0.2880 | 1.53 | | |
| | 0.5495 | 0.8034 | 0.2879 | 1.53 | | |
| | 0.8195 | 0.8034 | 0.4342 | 1.52 | 1.52 | |
| | 0.8195 | 0.8034 | 0.4328 | 1.52 | | |
| Vascular bundles | 1.1388 | 0.8034 | 0.6051 | 1.51 | 1.52 | 1.515 |
| | 1.1388 | 0.8034 | 0.5989 | 1.53 | | |
| | 1.1742 | 0.8015 | 0.6261 | 1.51 | 1.51 | |
| | 1.1742 | 0.8015 | 0.6255 | 1.51 | | |
| | 1.1742 | 0.8015 | 0.6230 | 1.51 | | |
| Outer shell | 1.4229 | 0.8034 | 0.7550 | 1.51 | 1.52 | 1.52 |
| | 1.4229 | 0.8034 | 0.7545 | 1.51 | | |
| | 1.4229 | 0.8034 | 0.7469 | 1.53 | | |
| | 1.4229 | 0.8034 | 0.7446 | 1.54 | | |
| | 1.4229 | 0.8034 | 0.7426 | 1.54 | | |
| | 1.6521 | 0.8034 | 0.8769 | 1.51 | 1.515 | |
| | 1.6521 | 0.8034 | 0.8754 | 1.52 | | |
| | 2.3778 | 0.8015 | 1.2560 | 1.52 | 1.52 | |
| | 2.3778 | 0.8015 | 1.2560 | 1.52 | | |

Table VII

Specific Gravity of Parenchymatous and Vascular Fractions of the Mature Cornstalk, Genetically Pure Strain 201, Weak.

| Tissue | S = Weight of sample | $D_1$ = Specific gravity of alcohol. | $(A_1-A)$ = Weight of alcohol displaced by sample | $D=\frac{S \times D_1}{(A_1-A)}$ | Average specific gravity of each sample. | Average specific gravity of each tissue. |
|---|---|---|---|---|---|---|
| Central cylinder | 1.2407 | 0.8076 | 0.6648 | 1.510 | 1.52 | 1.515 |
| | 1.2407 | 0.8076 | 0.6586 | 1.520 | | |
| | 1.2407 | 0.8076 | 0.6586 | 1.520 | | |
| | 2.0616 | 0.8076 | 1.1035 | 1.510 | 1.51 | |
| | 2.0616 | 0.8076 | 1.0993 | 1.510 | | |
| | 2.0616 | 0.8076 | 1.0993 | 1.510 | | |
| Outer shell | 1.0397 | 0.8076 | 0.5545 | 1.510 | 1.52 | 1.515 |
| | 1.0397 | 0.8076 | 0.5523 | 1.520 | | |
| | 1.0397 | 0.8076 | 0.5521 | 1.520 | | |
| | 1.2182 | 0.8076 | 0.6506 | 1.510 | 1.51 | |
| | 1.2182 | 0.8076 | 0.6522 | 1.510 | | |
| | 1.2182 | 0.8076 | 0.6513 | 1.510 | | |

Table VIII

Specific Gravity of Parenchymatous and Vascular Fractions of the Mature Cornstalk, Genetically Pure Strain 201, Strong.

| Tissue | S = Weight of sample | $D_1$ = Specific gravity of alcohol. | $(A_1-A)$ = Weight of alcohol displaced by sample | $D=\frac{S \times D_1}{(A_1-A)}$ | Average specific gravity of each sample. | Average specific gravity of each tissue. |
|---|---|---|---|---|---|---|
| Central cylinder | 1.1100 | 0.8076 | 0.5965 | 1.500 | 1.51 | 1.51 |
| | 1.1100 | 0.8076 | 0.5924 | 1.510 | | |
| | 1.1100 | 0.8076 | 0.5912 | 1.520 | | |
| | 1.1100 | 0.8076 | 0.5912 | 1.520 | | |
| | 1.1459 | 0.8076 | 0.6145 | 1.510 | 1.51 | |
| | 1.1459 | 0.8076 | 0.6136 | 1.510 | | |
| | 1.1459 | 0.8076 | 0.6136 | 1.510 | | |
| | 1.9136 | 0.8076 | 1.0251 | 1.510 | 1.51 | |
| | 1.9136 | 0.8076 | 1.0220 | 1.510 | | |
| | 1.9136 | 0.8076 | 1.0207 | 1.510 | | |
| Outer shell | 2.0655 | 0.8076 | 1.1001 | 1.520 | 1.52 | 1.52 |
| | 2.0655 | 0.8076 | 1.0975 | 1.520 | | |
| | 2.0655 | 0.8076 | 1.0969 | 1.520 | | |
| | 1.5339 | 0.8076 | 0.8170 | 1.520 | 1.52 | |
| | 1.5339 | 0.8076 | 0.8176 | 1.510 | | |
| | 1.5339 | 0.8076 | 0.8163 | 1.520 | | |

Table IX

Specific Gravity of Parenchymatous and Vascular Fractions of the Mature Sugar Cane.

| Tissue | S = Weight of sample | $D_1$ = Specific gravity of alcohol. | $(A_1-A)$ = Weight of alcohol displaced by sample | $D=\frac{S \times D_1}{(A_1-A)}$ | Average specific gravity of each sample. | Average specific gravity of each tissue. |
|---|---|---|---|---|---|---|
| Outer vascular shell | 5.9878 | 0.8076 | 3.2217 | 1.50 | 1.50 | 1.50 |
| | 5.9878 | 0.8076 | 3.2129 | 1.50 | | |
| | 5.9878 | 0.8076 | 3.2129 | 1.50 | | |
| | 5.5792 | 0.8076 | 3.0041 | 1.50 | 1.50 | |
| | 5.5792 | 0.8076 | 3.0031 | 1.50 | | |
| | 4.0671 | 0.8033 | 2.1956 | 1.49 | 1.49 | |
| | 4.0671 | 0.8033 | 2.1900 | 1.49 | | |
| Vascular bundles | 1.7304 | 0.8033 | 0.9387 | 1.48 | 1.49 | 1.49 |
| | 1.7304 | 0.8033 | 0.9374 | 1.48 | | |
| | 1.7304 | 0.8033 | 0.9257 | 1.50 | | |
| | 1.7304 | 0.8033 | 0.9215 | 1.51 | | |
| | 1.7304 | 0.8033 | 0.9234 | 1.50 | | |
| | 2.1914 | 0.8033 | 1.1832 | 1.49 | 1.49 | |
| | 2.1914 | 0.8033 | 1.1831 | 1.49 | | |
| Pith | 2.2142 | 0.8076 | 1.1711 | 1.53 | 1.53 | 1.52 |
| | 2.2142 | 0.8076 | 1.1708 | 1.53 | | |
| | 1.5880 | 0.8076 | 0.8557 | 1.50 | 1.50 | |
| | 1.5880 | 0.8076 | 0.8531 | 1.50 | | |
| | 1.5880 | 0.8076 | 0.8548 | 1.50 | | |

Table X

Specific Gravity of Parenchymatous and Vascular Fractions of the Mature Sorghum Cane.

| Tissue | S = Weight of sample | $D_1$ = Specific gravity of alcohol. | $(A_1-A)$ = Weight of alcohol displaced by sample | $D=\frac{S \times D_1}{(A_1-A)}$ | Average specific gravity of each sample. | Average specific gravity of each tissue. |
|---|---|---|---|---|---|---|
| Central cylinder | 1.8391 | 0.8076 | 0.9900 | 1.500 | 1.503 | 1.503 |
| | 1.8391 | 0.8076 | 0.9864 | 1.506 | | |
| | 2.3301 | 0.8076 | 1.2533 | 1.502 | 1.503 | |
| | 2.3301 | 0.8076 | 1.2489 | 1.507 | | |
| | 2.3301 | 0.8076 | 1.2534 | 1.501 | | |
| | 2.3301 | 0.8076 | 1.2536 | 1.501 | | |
| Outer shell | 4.2907 | 0.8076 | 2.3057 | 1.503 | 1.503 | 1.502 |
| | 4.2907 | 0.8076 | 2.3061 | 1.503 | | |
| | 4.2381 | 0.8076 | 2.2806 | 1.501 | 1.501 | |
| | 4.2381 | 0.8076 | 2.2783 | 1.502 | | |
| | 4.2381 | 0.8076 | 2.2777 | 1.503 | | |
| | 4.2381 | 0.8076 | 2.2825 | 1.500 | | |
| | 4.2381 | 0.8076 | 2.2826 | 1.500 | | |

Table XI

Specific Gravity of Parenchymatous and Vascular Fractions of the Mature Jerusalem Artichoke Stem.

| Tissue | S = Weight of sample | $D_1$ = Specific gravity of alcohol. | $(A_1-A)$ = Weight of alcohol displaced by sample | $D=\frac{S \times D_1}{(A_1-A)}$ | Average specific gravity of each sample. | Average specific gravity of each tissue. |
|---|---|---|---|---|---|---|
| Pith | 3.0594 | 0.8076 | 1.6046 | 1.540 | 1.536 | 1.540 |
| | 3.0594 | 0.8076 | 1.6134 | 1.532 | | |
| | 2.9375 | 0.8076 | 1.5366 | 1.544 | 1.544 | |
| | 2.9375 | 0.8076 | 1.5371 | 1.543 | | |
| Vascular shell | 11.9230 | 0.8076 | 6.8461 | 1.406 | 1.406 | 1.406 |
| | 11.9230 | 0.8076 | 6.8461 | 1.406 | | |
| | 11.9230 | 0.8076 | 6.8412 | 1.408 | | |
| | 6.5289 | 0.8076 | 3.7543 | 1.404 | 1.407 | |
| | 6.5289 | 0.8076 | 3.7545 | 1.404 | | |
| | 6.5289 | 0.8076 | 3.7320 | 1.413 | | |

obtained by the Willstatter method, he has suggested that more nearly correct results are probably obtained at ice box temperature than at room temperature. A similar difference was observed in the lignin content of parenchymatous and vascular material of sugar cane when the analyses were run at ice box temperature. No analyses were made at room temperature due to an insufficient supply of material. The unexplained effect of temperature on lignin analyses suggests that lignin content so determined is of doubtful value in a comparison of plant tissues. This data is neither extensive enough, nor is the method sufficiently refined to warrant the statement that these tissues are chemically identical. It does seem to indicate that they are more nearly alike chemically than is generally supposed. The objection may be raised that in most cases pure tissues have not been dealt with. For example, it may be suggested that the vascular tissue of the cornstalk consists of a mixture of tissues whose cell walls are decidedly different chemically, but which are present in such proportions that the average specific gravity and composition, as shown by such methods of analysis, equal that of the pith, a purely parenchymatous tissue. At present no experimental proof that such is not the case can be offered. However, it seems unlikely that such an averaging occurs in all the plants mentioned above.

The parenchymatous and vascular material of the Jerusalem artichoke differ both in specific gravity and in lignin con-

tent. Even here, however, the results on pentosans, cellulose, and even on lignin, indicate that these tissues are not totally dissimilar. Although the specific gravity and lignin values obtained on the parenchyma and vascular material of the Jerusalem artichoke might suggest that tissues of different percentage composition are characterized by a difference in specific gravity, no generalization of this import is warranted due to the doubtful value of lignin analyses referred to above and to the fact that some tissues having approximately equal specific gravity show a difference in lignin content as great as that reported for Jerusalem artichoke (table V).

B. Study of Acetylated Parenchymatous and Vascular Tissues of the Cornstalk.

The wall constituents of the cornstalk, namely: lignins, pentosans, and cellulose, are characterized by the presence of free hydroxyl groups. If these constituents are present in the parenchymatous and vascular tissues in the same proportion by weight and are associated in the same manner, the hydroxyl content of these tissues will be the same. The presence of an equal hydroxyl content may suggest, but will not prove the chemical identity of these tissues. On the other hand, a difference in hydroxyl content may be considered as conclusive evidence for the existence of a chemical difference between the parenchyma and vascular tissue.

## Method

No satisfactory method is available for the direct determination of hydroxyl content in cell wall material. Fuchs' (6) work on acetylated wood suggests that acetylation of the tissues of the cornstalk with acetic anhydride may result in the substitution of acetyl groups for hydroxyl groups, giving a product insoluble in the reagents used. If it is assumed that only the hydroxyl groups are subject to acetylation, the increase in acetyl content after acetylation may be considered as a measure of the hydroxyl content of the original tissue.

The materials used in the acetylation were air dried, water extracted tissues ground to pass a 60 mesh screen. The acetylation was carried out according to the method suggested by Fuchs (6). Thirty grams of the vascular shell of the stalk were added, during a one and one-half hour interval, to an acetylating mixture consisting of 0.4 grams of concentrated sulphuric acid in 175 grams of acetic anhydride. The mixture was stirred constantly with an electric stirrer and was cooled during the addition of tissue by immersing in ice. The temperature was then raised to 55 - 60°C. for two hours. Three hundred and thirty cubic centimeters of benzene were added, and the mixture was cooled to room temperature and stirred for one and one-half hours. The material was filtered by suction and washed with benzene. The product was allowed to stand over night in a large quantity of methyl alcohol and was well washed, first, with methyl alcohol, and then with ether. Sixteen grams of hand separated pith were similarly acetylated using an equal volume of acetylating mixture. This increased proportion of acetylating mixture seemed necessary to penetrate the more bulky tissue of the pith.

Acetyl analyses were made on tissues dried in a vacuum oven at 55°C. by a modification of the method of Ost and Katayama (15). A 1.0 gram sample was allowed to stand twenty-four hours in 10 cc. of 1:1 sulphuric acid, was diluted with 100 cc. of distilled water, and was steam distilled at such a rate that ten to twelve hours were required for the collection

of three liters of distillate. The acetyl content of the tissue was calculated from the following formula:

$$\frac{V \times N \times (CH_3CO)}{S \times 10} = A,$$

where V is the cubic centimeters of alkali of normality, N, required to neutralize the distillate from the sample, S, and A is the percent acetyl. The total acetyl content will include the small original acetyl content as well as the increase in acetyl due to the acetylation of free hydroxyl groups.

## Results

Thirty-seven grams of acetylated product were obtained from 30 grams of vascular shell, while only 14 grams of product were obtained from 16 grams of pith. The decrease in weight shown by the pith, suggested that some part of the original or acetylated material was soluble in the reagents used. Examination of the acetylating mixtures which had been used on pith and vascular tissue showed the presence of dissolved material. No attempt to identify this material was made.

The analytical results for the acetylated tissues are shown in table XII. These results indicate that the acetylated products obtained from the two tissues are chemically different. Whether this also indicates that the original tissues are different, seems open to discussion. If it is as-

Table XII

Analyses of Acetylated Parenchymatous and Vascular Tissues.

| Tissue | S = sample | V = cc. alkali | N=normality of alkali | A=% acetyl | $\frac{VxNx(CH_3CO)}{S \times 10}$ |
|---|---|---|---|---|---|
| Acetylated pith | 1.1069 | 122.07 | 0.0923 | 43.7 | 43.4 |
| | 0.7524 | 81.55 | 0.0923 | 43.0 | |
| Acetylated vascular pith | 0.9833 | 81.33 | 0.0923 | 32.8 | 32.7 |
| | 0.9002 | 73.86 | 0.0923 | 32.6 | |

sumed that the material dissolved by the acetylating mixture consisted entirely of unchanged cell wall tissue or of the acetylated product of the wall as a whole, such a conclusion is warranted. It seems equally probable, however, that the acetylating mixture dissolves the different wall constituents at an unequal rate. If this is the case, the product obtained is clearly not the product of the acetylation of the cell wall as a whole. Since the conditions favoring solution were not the same during the acetylation of the two tissues, it is not strange, regardless of the nature of the original tissues, that the products are not identical. Thus, the higher acetyl content found in the product obtained by the acetylation of the pith may be the result of a more complete solution, than occurred in the vascular material, of some wall constituent low in original acetyl or hydroxyl content. Comparison of the products obtained by reacetylation to con-

stant composition, should offer more reliable results. The difficulty encountered in securing sufficient quantities of hand separated tissues for such work makes it impractical. In view of these complications, acetylation under the described conditions does not offer a satisfactory method for a chemical comparison of the parenchymatous and vascular tissues of the cornstalk.

C. Study of the Location of the Cell Wall Constituents of Parenchymatous and Vascular Tissues of the Mature Cornstalk.

The chemical composition of the morphologically distinct layers of the plant cell wall has already been the subject of a considerable amount of research. This work has consisted of subjecting sections of the tissue under investigation to microscopic examination (a) after treatment with staining reagents which are supposedly specific for certain of the cell wall constituents, and (b) during or after treatment with solvents which are assumed to have a selective action on the wall. The first method has been the more popular of the two, probably because it gives a more distinct difference in visual appearance. Since the factors determining differences in staining reaction are still a matter of conjecture, conclusions based on such results are open to severe criticism. Furthermore, at least some of the stains are not specific for the substances they have been used to detect (4)(8).

The second method seems to be the more reliable of the two. By carrying out the treatments under conditions selected for standard analytical procedures the microchemical and analytical results may be qualitatively correlated. Obviously, this work is open to the criticisms raised to analytical procedures based on solubilities (page 8 ). This method has the further disadvantage that the tissues are frequently so distorted that the various wall layers become indistinguishable, thus increasing the difficulty of interpreting results.

According to the generally accepted view of cell wall chemistry, the middle lamella or primary wall is composed of pectin in some form, while the secondary and tertiary layers consist of cellulose, cellulose and lignin, cellulose and pectin, etc. This generalization is largely based on the work of Mangin (9 - 14), who studied sections of various plant tissues according to both of the above methods. Allen (1), using only staining methods, extended this work to a greater number of plant tissues and confirmed Mangin's findings.

More recently, Ritter (20) by the use of solvents employed in standard analytical procedures has shown that the middle lamellae of at least a number of mature woods consist chiefly of lignin, while the secondary walls consist of cellulose and lignin. This work has caused a renewal of interest in this phase of cell wall chemistry. Harlow (7) has reported that he was able to check Mangin's results on parenchyma and young woody tissue, and Ritter's results on mature woods. The absence of pectin in the mature cornstalk (17) suggests that the middle lamellae of all parenchymatous tissues are not composed of pectin bodies. The question of the composition of the primary and secondary walls of the tissues of the cornstalk is of interest in this connection, as well as in a general comparison of these tissues.

## Method and Results

The present study was limited to a microscopic examina-

tion of tissues which had been treated, as exactly as possible, according to the procedures used in obtaining the analytical results previously reported (page 8). This was considered desirable in order that the terms, lignin, cellulose, etc., might have the same meaning throughout the entire series of investigations.

In view of the prevalence of the idea that the middle lamellae of such tissues are chiefly composed of pectin, it was considered of interest to observe the action of standard pectin solvents on sections cut from the central cylinder of the mature stalk. Two and five-tenths percent ammonium oxalate solution was found to have no apparent solvent action on the tissues after a treatment of four hours at boiling water-bath temperature and twenty hours at room temperature. Similar results were obtained when a more drastic reagent, 2.5% sulphuric acid, was substituted for the oxalate solution. Such results indicate that the middle lamellae of the cornstalk are not chiefly composed of pectic bodies, and are in accord with the analytical results obtained by Peterson and Hixon (17).

Observation was first centered on tissues which had been practically freed from pentosans and lignin by a modification of the de Vain's process. Short lengths of vascular bundles, and small pieces of hand separated pith of the mature cornstalk were boiled thirty minutes in 1% sodium hydroxide, washed, chlorinated in water suspension thirty minutes, washed, boiled five minutes in 2% sodium sulphite, and washed.

In order to protect the material from physical injury, all filtering was accomplished by pouring the liquid out through a fine piece of cheese cloth stretched across the top of the container. In general, the bundles and pieces of pith retained their original form during this treatment. The delignified bundles were separated, with comparative ease, into individual cells by mounting under a cover glass and subjecting to slight pressure. When small pieces of delignified pith were similarly treated, the cell walls crumpled and folded to such an extent that the cell structure became practically indistinguishable. This crumpling is probably due to the thinness of the walls of the pith cells. Separation into individual cells was readily accomplished by placing a small piece of delignified pith in water in a U tube and shaking for twenty-four hours on a shaking machine in such a way that the water washed rapidly back and forth over the material. A suspension of individual cells, which resembled cubical crystals to the naked eye, resulted. Since untreated bundles and pith showed no tendency to separate into individual cells even under more severe physical treatment, it was assumed that the de Vain's process had resulted in the solution of the layer holding the cells together, i.e., the middle lamella, in both the pith and vascular tissue. The failure of the cells to separate during the chemical treatment (i.e., without some mechanical assistance) may probably be attributed to the character of the surface of the cellulose, and in the case of the

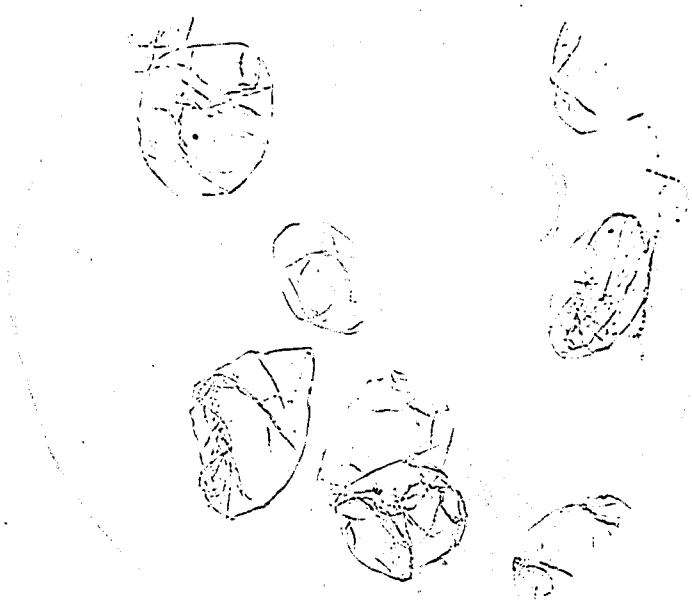

Plate I

Individual cells removed from a mass of delignified cornstalk pith by mechanical means.

vascular tissue to the way in which the long tapering cells fit together. Cells corresponding in structure to all the types of cells found in untreated tissue were observed in the pulp resulting from the delignified tissues. Plate I is a photomicrograph of cells of the pulp prepared from delignified pith. The results of these observations indicate that the middle lamellae of the vascular tissue and the fundamental parenchyma consist of lignin or pentosans, while the secondary walls contain an appreciable amount of cellulose.

Tissues from which cellulose and pentosans had been removed by the action of 72% sulphuric acid were next examined. Cross sections, 50 microns thick, were cut from paraffin embedded cubes of the central cylinder of the stalk. Sections from which the paraffin had been removed with chloroform, and which had been washed, first with alcohol, and then with water, were mounted in 72% sulphuric acid. Very rapid action occurred, resulting in almost immediate fragmentation of the section. At first a fragmentary network was visible in the region of the pith, but this gradually disappeared leaving only a residue of fine particles. A continuous and dense network persisted in the xylem and sclerenchyma of the bundle even after several days acid treatment. Only fragmentary material remained in the region of the phloem and bundle parenchyma. The persistence of a network in the xylem and sclerenchyma indicates that the middle lamellae of these tissues largely consist of lignin. The detection of such character-

Plate II

Cross section of cornstalk pith showing partial fragmentation produced by ten minutes treatment with 72% sulphuric acid. Complete fragmentation occurs after twenty to thirty minutes treatment.

Plate III

Lignin residue of a vascular bundle of the cornstalk, showing continuous lignin network and rings.

istic wall structures as rings and spirals in the lignin residue of the vascular tissue indicates that the secondary walls of this tissue contain an appreciable amount of lignin as well as of cellulose. That such structures are not due to cellulose that has not been attacked by the acid is shown by the ready solution of this residue when subjected to the de Vain's treatment.

While failure to obtain a continuous network in the pith, phloem, and bundle parenchyma does not show the presence of considerable lignin in the middle lamellae of these tissues, neither does it prove its absence. It is not unreasonable to suppose that the middle lamellae of these tissues are so thin that even though they consist entirely of lignin they would be easily fragmented. Furthermore, if the middle lamellae consist of pentosans and lignin, the removal of the former would increase the tendency of the residual lignin framework to break. For these reasons, no conclusions can be drawn concerning the distribution of lignin between primary and secondary wall layers in the pith, phloem, and bundle parenchyma.

Unfortunately, no solvent is known which dissolves lignin and cellulose and leaves pentosans, or which dissolves pentosan material only. For this reason, no definite conclusions concerning the exact location of this constituent can be drawn. Failure to find any evidence that any wall structure (with the possible exception of the middle lamellae of the pith, phloem, and bundle parenchyma) consists mainly of pento-

sans suggests that this constituent is probably present with the lignin or cellulose in one or both of the wall layers.

While the results presented above do not offer conclusive proof that the wall constituents are similarly located in parenchymatous and vascular tissues of the mature cornstalk, they offer little evidence that such is not the case. Thus it has been shown that the secondary walls in both tissues contain an appreciable amount of cellulose while the middle lamellae consist mainly of lignin or pentosans. The presence of lignin has been demonstrated in both primary and secondary wall layers of xylem and sclerenchyma. Failure to duplicate these results in the pith, phloem, and bundle parenchyma is not considered reliable evidence that the wall constituents are differently located in these tissues.

D. Microscopic Study of Cellulose Pulps Prepared from Parenchymatous and Vascular Tissues of the Cornstalk.

The properties of paper are in part determined by the properties of the individual cells in the pulp from which it is prepared. For this reason, a microscopic study of cellulose pulps prepared from the tissues of the cornstalk is of practical interest. For the sake of comparison, the present study was confined to properties which had been previously studied in wood pulps.

## Method and Results

### Measurements of the cells of the pulps.

Measurements were made, by means of an eyepiece micrometer, on cells of pulps prepared by a modification of the de Vain's process. The results are presented in table XIII. The corresponding data for a number of broad-leaved woods are shown in table XIV. It may be seen from these tables, that although the dimensions of a typical broad-leaved wood fiber are less than those of a typical cornstalk fiber, the ratio of length/width is of the same order in the two cases.

The formation of a mat is due to the interlacing of fibers, and to the cohesion of the surfaces of the cellulose cells. The extent to which interlacing will occur will largely depend on the length/width ratio of the fibers. In view of this fact, it is not surprising that mats of similar properties may be

Table XIII

Measurements of Cells of Cornstalk Pulp

| Type Cell | Length: No. of cells measured* | Length: Mm. Average | Length: Mm. Maximum | Length: Mm. Minimum | Width: No. of cells measured* | Width: Mm. Average | Width: Mm. Maximum | Width: Mm. Minimum | Average ratio: length/width |
|---|---|---|---|---|---|---|---|---|---|
| Fiber | 202 | 5.52 | 23.15 | 1.01 | 177 | 0.167 | 0.30 | 0.07 | 33 |
| Pith | 199+ | 1.43 | 2.66 | 0.40 | + | | | | 1+ |

*Three or four typical cells were measured on each of a large number of mounts.

+Since it is impossible to differentiate between length and width in pith cells, all measurements were used in the construction of one average value.

Table XIV*

Dimensions of Fibers of Some Broad-leaved Woods

| Wood | Average length | Average width | Average ratio: length/width |
|---|---|---|---|
| Beech (Fagus grandifolia) | 1.13 | 0.022 | 51 |
| Largetooth aspen (Populus grandidentata) | 1.08 | 0.028 | 39 |
| Aspen (Populus tremuloides) | 1.15 | 0.032 | 36 |
| Tupelo gum (Nyssa aquatica) | 1.85 | 0.066 | 28 |
| Red alder (Alnus rubra) | 1.23 | 0.027 | 45 |
| Sycamore (Platanus occidentalis) | 1.57 | 0.024 | 65 |
| Red maple (Acer rubrum) | 0.93 | 0.020 | 46 |
| Buckeye (Aesculus flava) | 0.62 | 0.020 | 31 |
| Cucumber magnolia (Magnolia acuminata) | 0.86 | 0.029 | 29 |
| Umbrella (Magnolia fraseri) | 1.08 | 0.027 | 40 |
| Yellow poplar (Liriodendron tulipifera) | 1.14 | 0.029 | 39 |
| Red gum (Liquidamber styraciflua) | 1.55 | 0.031 | 50 |
| Black gum (Nyssa sylvatica) | 1.68 | 0.026 | 65 |
| American elm (Ulmus americana) | 1.35 | 0.019 | 71 |
| Paper birch (Betula papyrifera) | 1.17 | 0.025 | 47 |

*Constructed from experimental data reported by Sutermeister (23).

prepared from cornstalk and wood fibers. Obviously, in the case of cells of a length/width ratio equal to one, mat formation will not be due to an interlacing of fibers. Such a mat would be expected to differ in properties from one of the interlaced type. A comparison of the papers prepared from pulps prepared from parenchymatous and vascular tissues of the cornstalk show that the facts are in agreement with this prediction.

Disintegration of the cells of the pulps by phosphoric acid-absolute alcohol treatment.

Delignified vascular bundles of the cornstalk were dehydrated in alcohol, subjected to swelling and shrinking by treating alternately with phosphoric acid and absolute alcohol, and finally mounted in acid. Sixty-eight, seventy-six, and eighty-five percent phosphoric acids were used. The time allowed for the individual treatments varied from three to fifteen minutes. The swollen cells were subjected to slight pressure by pressing on the cover glass, and were examined under the microscope.

Typical fiber or tracheid cells were first examined. Under the described treatment the cellulose wall separated into several concentric layers (plate IV). Solution of the various layers was preceded by striation and separation into spirally wound fibrils. The fibrils of the outer layer form an angle of approximately 90 degrees to the long axis of the cell (plate V), while the fibrils of the inner layers are wound at

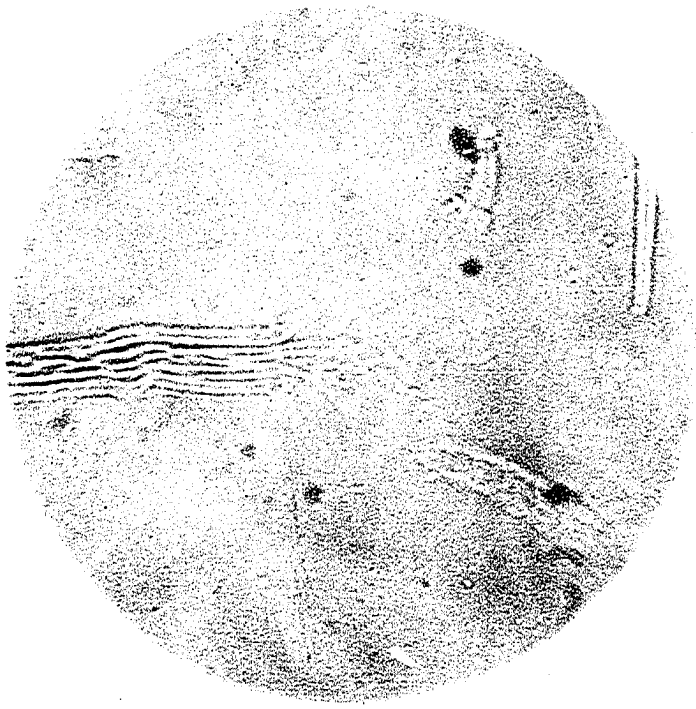

Plate IV

Separation of delignified cell wall of a fiber from the vascular bundle of a corn-stalk into four distinct layers by means of phosphoric acid-absolute alcohol treatment.

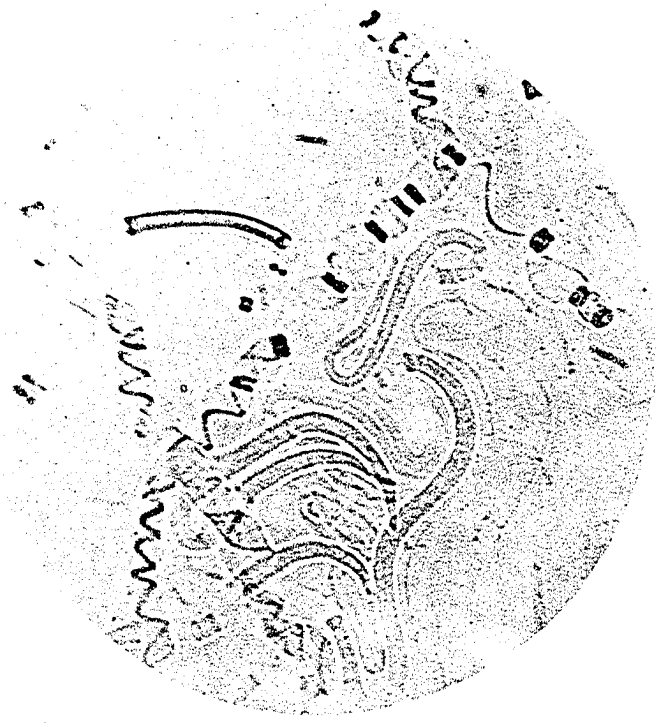

Plate V

Transverse swelling of inner layers of cornstalk fiber at places where the outer spiral has been dissolved or has been pulled away from its normal 90 degree angle.

an angle of 30 to 45 degrees. (No satisfactory photomicrographs were obtained).

These observations agree with those of Ritter (19) on delignified elm fibers. He used this difference in orientation of the fibrils of the inner and outer layers to explain the difference in swelling exhibited by them. Similar behavior was observed in the cornstalk. Thus, as the outer wall dissolves away the inner layers rapidly swell outward with constrictions where the outer layer is still intact (plate VI). This apparent structural similarity of wood and cornstalk fibers suggests that the ability of the two fibers to stand stress and strain will be of the same order of magnitude.

An attempt to study the structure of the walls of parenchymatous pulp cells by the same method was unsuccessful. Crumpling and complete solution occurred so rapidly that no observations could be made. It seems possible that this difference in behavior may be due to the relative thinness of these walls rather than to any structural difference. Regardless of the factors responsible for this difference in behavior, it is obvious that these cells are less adapted to stand stress and strain than the fibers.

An interesting observation was made on the structure of the walls of the pitted vessels of the vascular material. Under the phosphoric acid-alcohol treatment the vessel walls, which apparently consist of only one layer, separate into

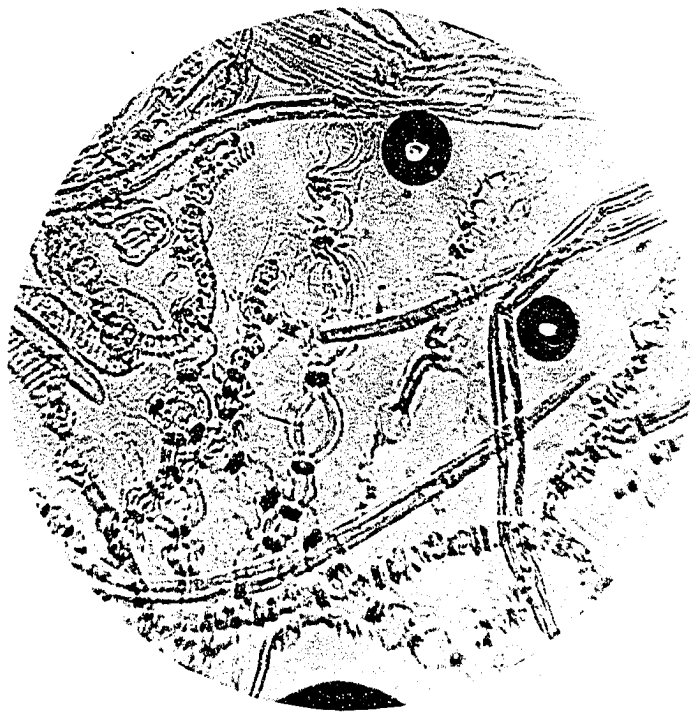

Plate VI

Transverse swelling of inner layers of cornstalk fibers at places where the outside layer has been dissolved.

fibrils wound at an angle of 45 to 90 degrees to the main axis of the vessel. The pits were found to be parallel to, and in some cases continuous with the limits of the fibrils.

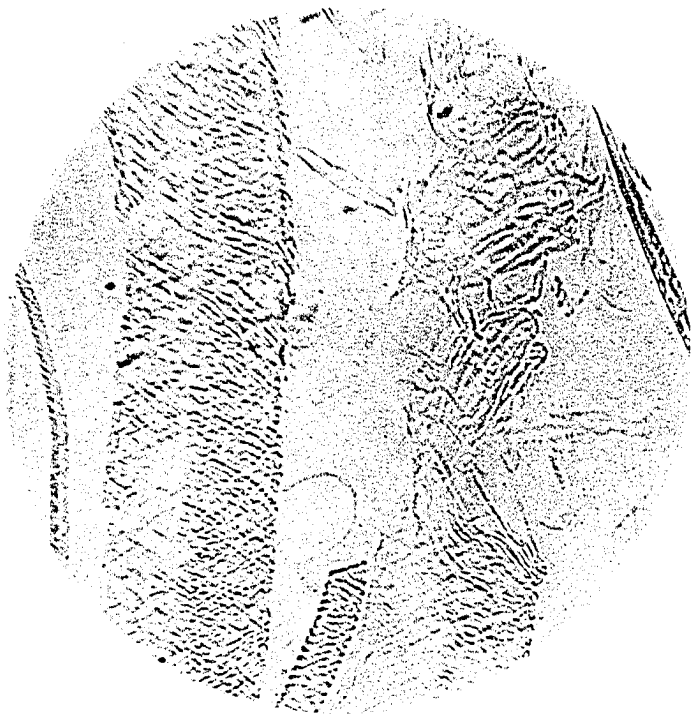

Plate VII

Delignified cell wall of a pitted vessel from the vascular bundle of a cornstalk showing the spirally wound fibrils after phosphoric acid-absolute alcohol treatment.

E. Microscopic Study of Several Wallboards.

The increased demand for insulating materials for building purposes, together with the attention recently devoted to the utilization of agricultural wastes, has resulted in the commercial production of insulating wallboards from a number of fibrous vegetable wastes. Wood waste, sugar cane bagasse, wheat straw, flax straw, extracted licorice root, and cornstalks are now utilized in this way.

The production of the board consists, first, of pulping the raw material, and second, of forming the board from the pulp. Pulping is accomplished by several different processes. The pulp is coarser than paper pulp, is usually higher in lignin and pentosans, and is less highly hydrated. The boards are formed by the separation of the pulp from water suspension on modified Foudrinier or cylinder machines.

The insulating properties of the commercial boards from fibrous materials are approximately the same. Boards prepared in the Iowa State College Chemical Engineering laboratory from mechanically separated cornstalk pith show insulating properties much superior to those of boards prepared from fibrous materials. The various boards as now produced differ somewhat as to strength.

A microscopic study of the structure of the various boards was undertaken to show any existing correlation between the structure, method of formation, and properties of the boards.

## Method and Results

Small blocks of various wallboards which had been softened by soaking in acetone were embedded in paraffin. Sections, 30 - 50 microns thick, were cut both parallel and perpendicular to the surface plane of the board. The paraffin was removed with xylol and the sections were mounted in Canada Balsam. The mounts were examined microscopically and photomicrographs were prepared. (Plates VIII - XV).

It was noted that the various tissues in any given board show some evidence of strain, but, in general, retain their identity; i.e., pith cells, tracheids, etc. may be distinguished. The structure of a board is, apparently, partly determined by the structure of the tissues used in its preparation. Thus, the difference in properties shown by corn pith board is probably to be attributed to the original subdivision of the tissue into large, thin walled, isodiametric cells. The material used in the preparation of a board may be determined by microscopic examination to the degree that it is possible to recognize the individual tissues of various plants. Thus, plates XIV and XV unmistakably represent boards prepared from wood.

The arrangement of the tissues in the several boards is very similar. In all cases, the fiber cells and groups of such cells cross each other at various angles and tend to lie with long axes parallel to the surface of the board. Groups

of fiber cells are more common than single cells in all boards examined except in "Masonite" (plate XV). In those boards containing parenchymatous tissues (plates VIII - XIII) the individual parenchyma cells, or more often groups of cells, are variously scattered about among the fibers. In no case was a definite arrangement of parenchyma cells with respect to fiber cells found to be characteristic of a board.

**Plate VIIIa**

Section cut parallel to the surface of a cornstalk board formed on a modified Foudrinier machine.

Plate VIIIb

Section cut perpendicular to the surface of a cornstalk board formed on a modified Foudrinier machine.

Plate IXa

Section cut parallel to the surface of a board formed from lime cooked cornstalks on a cylinder machine. The dense appearance of this board is due to residual lime.

Plate IXb

Section cut perpendicular to the surface of a board formed from lime cooked cornstalks on a cylinder machine. The dense appearance of this board is due to residual lime.

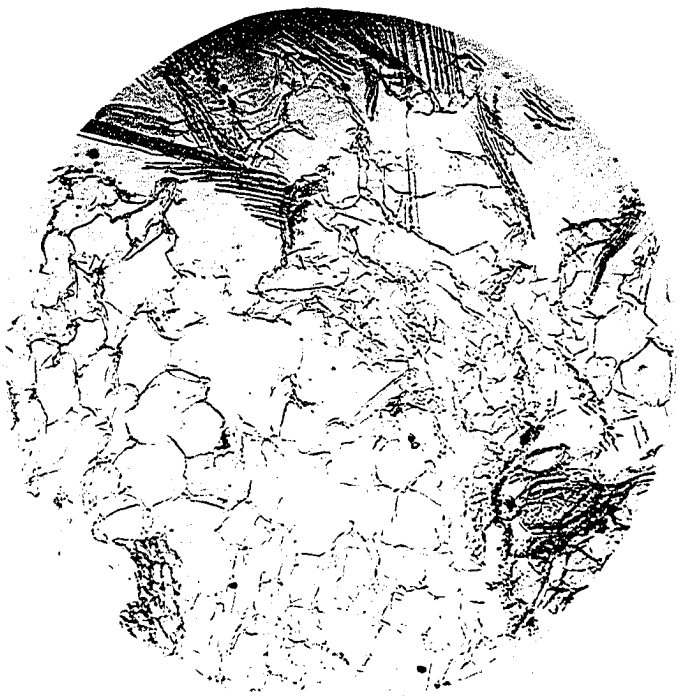

Plate X

Cornstalk pith board formed on a stationary screen.

Plate XI

Section cut parallel to the surface of "Maizewood", a board formed from cornstalk pulp on a modified Foudrinier machine.

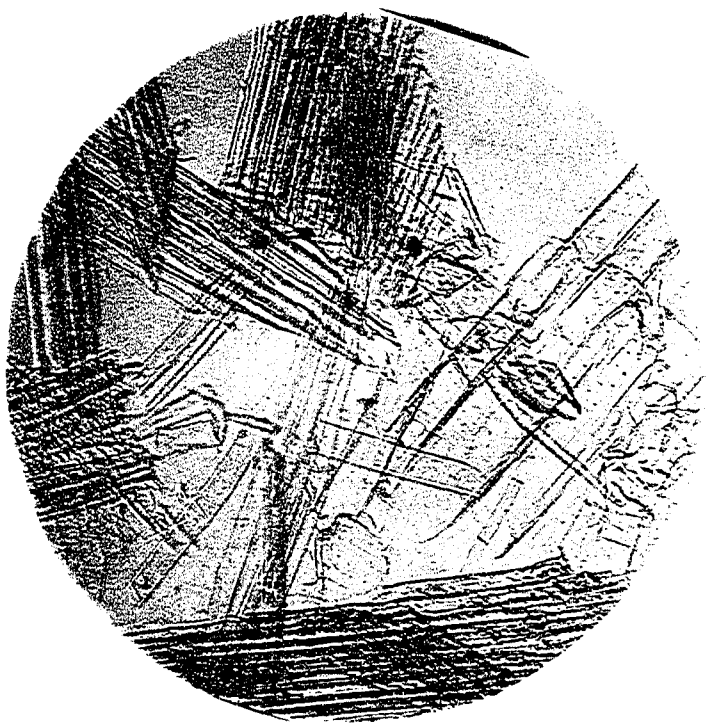

Plate XIIa

Section cut parallel to the surface of "Celotex", a board formed from sugar cane pulp on a cylinder machine.

Plate XIIb

Section cut perpendicular to the surface of "Celotex", a board formed from sugar cane pulp on a cylinder machine.

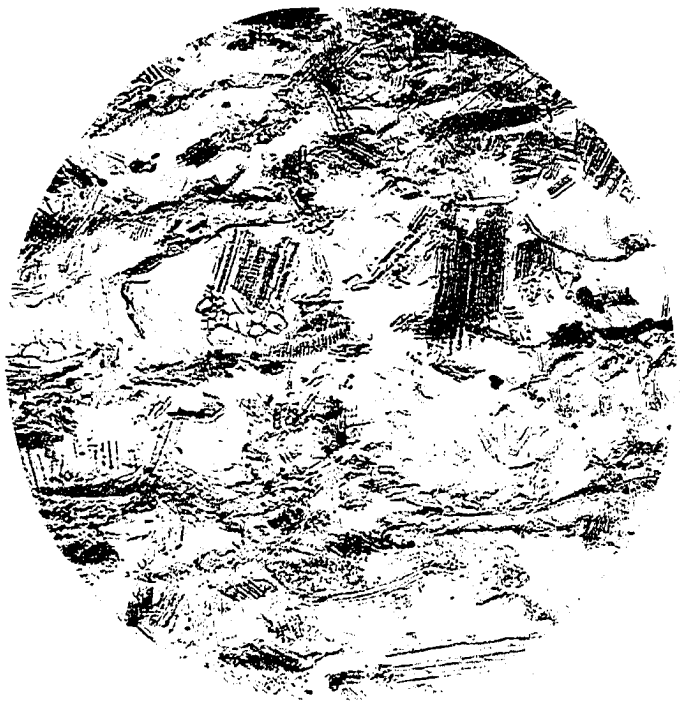

Plate XIII

Section cut perpendicular to the surface of "Inso Board", made from wheat straw pulp on a cylinder machine.

Plate XIVa

Section cut parallel to the surface of "Insulite", a board formed from wood waste pulp on a cylinder machine.

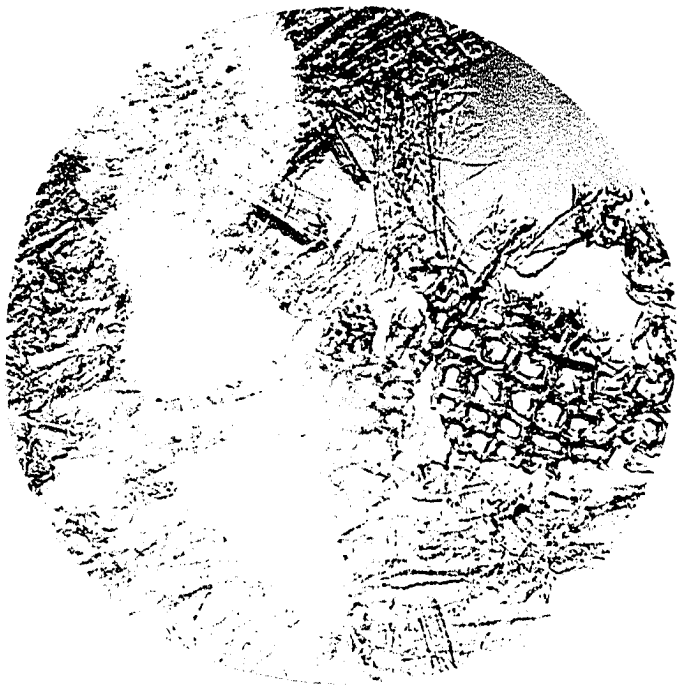

Plate XIVb

Section cut perpendicular to the surface of "Insulite", a board formed from wood waste pulp on a cylinder machine.

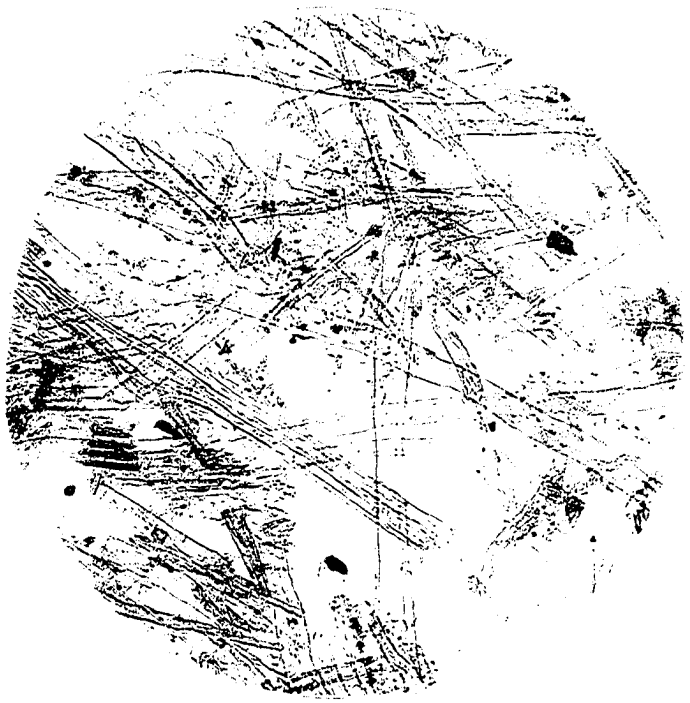

Plate XVa

Section cut parallel to the surface of "Masonite", a board formed from exploded wood fiber on a modified Foudrinier machine.

Plate XVb

Section cut perpendicular to the surface of "Masonite", a board formed from exploded wood fiber on a modified Foudrinier machine.

## GENERAL DISCUSSION

The results of the preceding series of investigations indicate that the cell walls of parenchymatous and vascular tissues of the mature cornstalk, and probably of mature plants in general, are more nearly chemically similar than has been supposed. Further work is necessary to determine the exact nature of any existing chemical differences. Such work calls for more refined methods than have so far been developed.

If such materials are not greatly different chemically, some other factor or factors must be largely responsible for the difference in properties exhibited by these tissues. Both microscopic examination and comparison of apparent and actual specific gravities indicate that their original mechanical subdivision is quite different. A greater surface of cell wall material is exposed in the pith, which has the smaller apparent specific gravity and which consists of large, thin walled, isodiametric cells, than in the vascular tissue which consists mainly of heavy walled, cylindrical cells with diameters many times less than that of an average pith cell. From the law of mass action and from generalizations regarding surface phenomena in colloids, it is to be expected that the pith will be more readily acted upon by chemical reagents. The facts are in accord with this prediction.

Peterson (16) has found that thermophilic bacteria fer-

ment the pith more rapidly than the vascular shell when both have been ground to pass a 60 mesh screen. Since such a fermentation is a surface reaction, this difference in ease of biological attack is to be expected. This worker has also found that vascular material which has been ground in a colloid mill ferments more rapidly than pith ground to pass a 60 mesh screen. This lends further support to the idea that many of the differences in properties shown by parenchyma and vascular tissue are largely due to the original mechanical subdivision of the tissues.

A difference in staining reaction is characteristic of parenchyma and xylem. If the cell walls of these tissues are chemically similar and have the same specific gravity, this difference must be explained in some other way than as the result of difference in either of these properties. It seems probable that this apparent difference in staining reaction may be partly an optical effect produced by different masses of the same material. This is comparable to the fact that a spool of thread appears darker than a single strand of the thread or than a piece of fabric woven from it.

The difference in properties exhibited by wallboards from parenchymatous and vascular tissues (page 52) may probably also be explained as the result of the original mechanical subdivision of the tissues. Dunlap (5) has suggested that the porosity of various woods determines their insulating properties. He defines porosity as the ratio of

$$\frac{\text{(the volume of a block of wood)-(the volume occupied by the cell wall material)}}{\text{(the volume of a block of wood)}}.$$

Since air is a poorer conductor of heat than cell wall material, the more porous tissue is the better insulating material. If the two tissues of the cornstalk are chemically similar, Dunlap's hypothesis may be used to explain differences in insulating properties shown by these boards. Furthermore, since the cell walls of these tissues, as shown by specific gravity (5)(18) and analytical data (21), do not seem to differ greatly from wood cell walls, any difference in insulating properties shown by these tissues and by woods may probably be attributed to their different porosities. The limiting apparent specific gravity of boards prepared from the two tissues of the cornstalk will be the same, namely, 1.52. The insulating power of such boards would be identical. Due to the great resistance to loss of identity shown by the cells of these tissues, even in pressure boards, the chance that boards of this limiting density will be prepared, save by the addition of some more dense material, is slight.

In view of the fact that the two tissues of the stalk yield the same substances in at least roughly the same proportions, the extent to which they may be practically utilized for the same purpose will probably depend on the extent of the influence of the cellular structure on the properties of the product. For example, in the preparation of paper and wallboards, the tissue used will depend on the properties of the

desired product. On the other hand, either or both tissues should be of approximately equal value in the preparation of fermentation products. Even where the tissues are to be utilized for the same purpose, the difference in reaction rate exhibited by these materials suggests that it may be desirable to subject them to treatments of different intensity.

## SUMMARY

1. Specific gravity and analytical data on parenchymatous and vascular tissues of several plants have been presented. Such data suggest that these tissues are more nearly alike chemically than is generally supposed.

2. An attempt has been made to measure the hydroxyl content of the two tissues of the cornstalk by determining the increase in acetyl content after acetylation. The results are of doubtful value due to the solution of some part of the material in the acetylating mixture.

3. It has been shown that the secondary walls of the parenchyma and xylem of the cornstalk contain an appreciable amount of cellulose, while the middle lamellae consist mainly of lignin or pentosans. The presence of lignin has been demonstrated in both primary and secondary layers of the xylem walls.

4. The dimensions and structure of cells of pulps prepared from the vascular tissue of the cornstalk have been compared and found to be similar to those prepared from woods, and apparently dissimilar from those obtained from the pith of the stalk.

5. A microscopic study of several wallboards has been made.

6. The probable importance of the effect of the original mechanical subdivision of tissues on their properties has been considered.

## LITERATURE CITED

1. Allen, C. E.
On the origin and nature of the middle lamella. Bot. Gaz., 32:1-34. 1901.

2. Association of Official Agricultural Chemists.
Methods of analysis. p.120. Association of Official Agricultural Chemists, Washington, D. C. 1925.

3. Burke, G. W.
Some analytical data on corncobs and their parts. Unpublished Thesis, Iowa State College Library. 1923.

4. Crocker, E. C.
An experimental study of the significance of "lignin" color reactions. Jour. Indus. and Engin. Chem., 13: 625-627. 1921.

5. Dunlap, F.
Density of wood substance and porosity of wood. Jour. Agr. Research (U.S.) 2:423-428. 1914.

6. Fuchs, W.
Zur Kenntnis des genuinen Lignins. I. Die Acetylierung des Fichtenholzes. Ber. Deut. Chem. Gesell., 61B:948-951. 1928.

7. Harlow, W. M.
The chemical nature of the middle lamella. Syracuse University. New York State College of Forestry (Bul.) III, no.2-a. Tech. Pub. No.30:5-11. 1930.

8. Harlow, W. M.
Contributions to the chemistry of the plant cell wall. III. The reliability of staining reagents in microchemical studies of plant cell walls. Syracuse University. New York State College of Forestry. Bul. I, no.4-b. Tech. Pub. No.26:3-13. 1928.

9. Mangin, L.
Observations sur la membrane cellulosique. Compt. Rend. Acad. Sci. (Paris), 113:1067-1072. 1891.

10. Mangin, L.
Sur la constitution de la membrane des végétaux. Compt. Rend. Acad. Sci. (Paris), 107:144-146. 1888.

11. Mangin, L.
Sur l'emploi du rouge de ruthénium en Anatomie végétale. Compt. Rend. Acad. Sci. (Paris), 116:653-656. 1893.

12. Mangin, L.
Sur la présence des composés pectiques dans la végétaux. Compt. Rend. Acad. Sci. (Paris), 109: 579-582. 1889.

13. Mangin, L.
Sur les reáctifs colorants des substances fondamentales de la membrane. Compt. Rend. Acad. Sci. (Paris), 111:120-123. 1890.

14. Mangin, L.
Sur la substance intercellulàire. Compt. Rend. Acad. Sci. (Paris), 110:295-297. 1890.

15. Ost, H. und Katayama, T.
Vergleichende Acetylierung von Cellulose, Hydrocellulose und alkalisierter Cellulose. Zeitschrift. für Angewandte Chemie., 25:1467-1470. 1912.

16. Peterson, C. J.
Analytical studies on the utilization of the cornstalk. Unpublished Thesis, Iowa State College Library. 1930.

17. Peterson, C. J. and Hixon, R. M.
Chemical examination of the tissue of the cornstalk. Indus. and Engin. Chem., Analytical Ed., 1:65-67. 1929.

18. Richter, E.
Einiges über das spez. Gewicht von Holz und Zellstoff. Wochenblatt für Papierfabrikation, 46:1529-1533. 1915.

19. Ritter, G. J.
Composition and structure of the cell wall of wood. Jour. Indus. and Engin. Chem., 20:941-945. 1928.

20. Ritter, G. J.
Distribution of lignin in wood. Indus. and Engin. Chem., 17:1194-1197. 1925.

21. Ritter, G. J. and Fleck, L. C.
Chemistry of wood. VI. The results of analysis of heartwood and sapwood of some American woods. Indus. and Engin. Chem., 15:1055-1056. 1923.

22. Schorger, A. W.
Chemistry of cellulose and wood. p.524. McGraw Hill Book Company, New York. 1926.

23. Sutermeister, E.
Chemistry of pulp and paper making. p.58. John Wiley and Sons, New York, 1929.

24. Wiley, H. W.
Composition of maize. U. S. Dept. Agr. Bur. of Chem., Bul.50. 1898.