VEGETABLE FIBER.

VEGETABLE FIBER, CONSIDERED WITH REFERENCE TO ITS STRUCTURE AND CHEMICAL PROPERTIES.

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Although the general structure of vegetable fiber has long been known, it is only within a few years that the rapid advances made in the science of vegetable anatomy, aided by improvements in the microscope, have cleared up much that was doubtful, and given us definite notions upon points which have a direct application to the processes of the arts. But few writers on vegetable anatomy have studied the subject with immediate reference to its technical applications, and it is only since the year 1852 that we have been furnished with minute and correct representations of the principal varieties of vegetable fiber.

The increasing want of paper-making material has stimulated the study of this subject, which, however, with few exceptions, has been attempted in the wrong direction, that is from a purely empirical point of view. The result has been, mainly, a revival of old and well-known processes, with immaterial alterations.

Our present object is to give an outline of the chemical properties and of the minute structure of vegetable fiber, a knowledge of which we consider as absolutely necessary before considering the technical or economical questions which may arise.

Owing, however, mainly to ignorance of the subject upon which we are about to treat, the economical questions themselves have been often misstated, and real advancement in the arts has been prevented by the unfavorable impression produced by the useless solution of such misstated questions. For instance, it is unwise and useless to attempt to supersede a well-established staple by another not fitted by nature to take its place. Long-continued agricultural and commercial relations cannot readily be overturned, even when they have not some well-founded reason for their continuance. The attempt to supersede cotton by the ultimate fiber of flax is a case in point. This project originated in England, more than a century ago, and, strangely enough, the effort to revive it has generally been prompted by purely social considerations. It requires but little knowledge of the respective structure of the two substances to understand that it is at least unprofitable to spoil good flax in order to make a poor imitation of cotton.

Again, many kinds of fiber might advantageously be used in cordage or in textile fabrics, and it must be evident that there would be no economy in breaking up such material at once to paper stuff, which might be made more readily and cheaply from the worn-out cordage or rags

from the same fiber. It is needless to multiply instances of this kind of misapplication. The true policy seems to be this: to introduce new materials to supply a demand for which they are directly fitted, and to leave existing materials to be used as before.

As questions which may be usefully considered, we will cite the following:

It is desirable to ascertain what fibers may be obtained from the dry regions of the Western plains, which, while favorable to such plants, are incapable of yielding any other profitable product of the soil.

Again, in some instances it may be found advantageous to increase the variety of fibrous substances produced in any given region, for circumstances which might prove disastrous to one crop might prove beneficial to another, and with this security the fortunes of whole districts would not be risked, as it were, upon the cast of a single die.

Another matter of great consequence in the economical consideration of fiber, is the difference between the supply from plants of spontaneous growth and from those which must be cultivated. Fibrous materials of spontaneous growth, for the most part, can only be brought to us from abroad; for, although the amount of uncultivated land in the United States may be large, it is not often that such lands abound in fibrous plants. The great plains of the West and the salt marshes of the sea-coast will probably be found the only parts of our territory from which a spontaneous growth of fibrous material of any kind can be obtained in great quantity. Every now and then we hear that some one of our common weeds has been found to furnish a good material for paper stuff; but if we stop to estimate the quantity furnished by each plant, it will often appear that the product of a whole State would be required for one issue of our large daily or weekly papers. When we come to the cultivation of fibrous plants, the character and quantity of the product at once decide the question of profit. It is not every plant which is capable of regular cultivation, or of attaining, in a cultivated state, the luxuriance of its spontaneous growth. Many of our weeds owe their great abundance, in certain localities, to some peculiar ingredient or condition of the soil, which cannot be easily or economically produced at pleasure.

Such are some of the points of view from which the economical considerations in regard to fiber should be made.

THE VEGETABLE CELL.

Cellulose.—We now proceed to the examination of the structure of vegetable fiber, which, like every other part of the plant, is made up of *cells*, and upon the shape of these cells and their mode of attachment to each other, the character of the fiber depends. Of common fibers, cotton is the only one formed of a single cell. As the cell is the ultimate organic element of all fibers, the study of its nature becomes the foundation of all real knowledge of this subject.

Every living cell is an entirely closed bag, or vesicle, whose external wall is formed of a substance called *cellulose*, identical in composition with starch.

Test for cellulose.—Starch is readily recognized by the blue color produced with a solution of iodine. This color, however, is not formed in cellulose by iodine alone, but the addition of sulphuric acid or of chloride of zinc readily brings it out. An exception to this reaction is found in the cells of some of the lower plants, which cannot, by any means, be made to give the blue color; nevertheless, analysis has shown that their chemical composition is identical with that of ordinary cellulose.

Chemical properties of cellulose.—The study of the chemical properties of the material of the cell wall is of the greatest importance to the arts. On the present occasion we must restrict ourselves to a few of the most striking, which, however, are those most often brought into use. For the demonstration of these properties we may employ clean cotton wool, old well-washed rags, of cotton or linen, or white paper made of cotton or linen, without the addition of mineral matter; materials which are so nearly pure cellulose that we may safely experiment upon them, instead of the substance more carefully prepared.

Although the more powerful chemical reagents have more or less action upon cellulose, one of its most remarkable properties is the resistance offered to the action of substances commonly considered as "corrosive."

Action of sulphuric acid.—The action of sulphuric acid (oil of vitriol) is remarkable, producing a series of changes of a very curious character. The first of these changes has already been referred to, as that which enables cellulose to give a blue color, with a solution of iodine, just as starch does. This change, however, is apparently but a mere transition to another condition, and the peculiar property only continues in the presence of the acid, for on the addition of water the blue color disappears, and cannot again be produced without a second treatment with acid.

If concentrated sulphuric acid is used in these experiments, the action becomes too violent to be observed in its successive stages; and if large quantities of material are employed, without the proper precautions, heat is produced, the cellulose is charred, and a new and different series of reactions commences.

When concentrated sulphuric acid, to which about one half its bulk of water has been added, is used, the cellulose swells, and is changed into a somewhat gelatinous mass, so that the individual cells become cemented or fused together. If the action is then arrested by the addition of water and some alkaline substance to neutralize the remaining acid, the cellulose is still found with the same chemical composition as before, although its physical properties are quite changed. Unsized paper subjected to such a treatment assumes, when dried, a parchment-like appearance, contracts in a remarkable degree, and no longer absorbs moisture, as the original paper did; in fact, except where holes occur, it has become water-proof. There will probably be many useful applications of this process, and it is to be regretted that the credit has been taken from the original discoverers, who long ago published the process and their investigations upon it, by those who have more recently chosen to re-discover what must have been known to every well-read chemist.

The prolonged action of strong sulphuric acid converts cellulose into *dextrine*, a substance soluble in water, and which is also obtained from starch. If water is added to the product, and the whole is boiled for some time, the dextrine is changed, by the further action of the acid, into grape sugar, which can be obtained pure when the acid is precipitated by lime. As the whole change from cellulose to grape sugar involves merely the taking up of the elements of water, clean linen or cotton rags, by such a process, yield more than their own weight of sugar. The economy of this mode of manufacturing grape sugar is, at least, doubtful, although it has recently received much attention in Europe. Owing to the low sweetening power of this sugar, its chief use is for fermentation into spirit for distillation. Even the most common waste material, such as saw dust, can probably be more profitably worked up into certain kinds of paper, than converted into spirit.

Action of nitric acid.—Strong nitric acid, applied with proper precautions, does not decompose cellulose, but enters into combination with it in various proportions, in one of which it forms the now well-known *gun-cotton*, in which the original structure of the fiber is not visibly altered. This substance, from its solubility in a mixture of alcohol and ether, (*collodium,*) is highly valuable, affording on its evaporation a very thin and continuous water-proof film. The applications of this useful property are now numerous, in photography, in surgery, &c.

Nitric acid, by removing other substances which may be present, enables us often to bring out the ultimate structure of the cell wall, which would not otherwise be visible.

Action of caustic potash, or soda, &c.—Dilute solutions of caustic potash, or soda, do not materially alter pure cellulose, while they possess the valuable property of dissolving nearly all of the substances which are attached to or contained in the cell wall, excepting only the cellulose itself. In general, all solutions of salts having an alkaline reaction have more or less of this property. We shall show, further on, that the solvent power of alkaline solutions renders them almost indispensable in making paper from other material than rags.

Nitrogenous matter contained in the cell.—We have hitherto treated of the properties of pure cellulose, but it must not be imagined that the wall of the cell is wholly made up of this substance. Every living vegetable cell is lined with a coating (partly solid and partly soft, or even fluid) of a compound containing nitrogen, and liable, under the influence of heat and moisture, to enter into decomposition, which in turn changes the cellulose itself. As the parts containing the cells "ripen," and cease to grow, this substance disappears, wholly or in part. The heart wood of trees, the hairs on ripe seeds, &c., contain less of this matter than the sap-wood or the fibers of a plant taken at the time of active growth. The presence of such a ferment in freshly gathered fiber is not to be disregarded, although it has been scarcely noticed in technical works on the subject. The terms "gluten" and "mucilage" have been used very vaguely and inaccurately, to denote both the nitrogenous matter and other substances having quite different properties. The processes usually prescribed for the preparation of various common fibers, such as hemp and flax, being derived from long established experience, do, in fact, though not distinctively, refer to the presence of such a substance. But, when these methods are to be transferred to new materials, under quite different conditions, it becomes necessary that we should understand the reason why such processes have been introduced, and if these, as in the present instance, are not generally known, it becomes the more important that they should be examined, in order that correct principles may guide new applications.

The presence of a ferment in fresh fiber is not without its use, for it aids in producing a partial decomposition in substances which it is desirable to remove, and which offer less resistance to such action than the cellulose itself. But an excess of this ferment will, unless it is removed or rendered inactive, endanger the strength of the product. With fibers drawn from plants in full activity of growth, in hot climates, this danger becomes serious, for under such circumstances, a few hours may do damage which elsewhere might require many days for its course. It must be remarked, too, that many, if not, indeed, most fibers, require for the attainment of the proper degree of softness and delicacy, to be gathered before the full maturity of the parts to which they belong. In proportion as this period is anticipated, will the nitrogenous or fermentiscible matter be present in greater quantity.

There are two different modes of dealing with this material. In the first place, it may be temporarily rendered inert by rapid drying. This plan is adopted in the milder climates, where such plants as flax and hemp, not very juicy at the time of maturity, are the usual fibrous products. The after treatment may then be commenced at pleasure, provided that the crop, in the meanwhile, is well guarded from moisture.

In the second place, this material may be removed, and at the same time produce the desired degree of fermentation, by the action of water, either while exposed to the air, as in the process of "dew-rotting," or when wholly immersed in water, as in "water-rotting." This latter process may be modified by using warm water, which hastens the desired action, leaving it, however, under the complete control of the operator. In this case, a thorough subsequent washing seems necessary to carry every vestige of the ferment. We need not dwell upon the merits claimed, respectively, for these different methods, our object simply being to point out the common principal upon which they depend with reference to the modifications required by new materials under new circumstances. We may remark, however, that very hot water would not answer, as it would, in great part, coagulate instead of dissolving the nitrogenous matter, and at the same time prevent the fermentation.

It is important to observe that we may entirely avoid the necessity for fermentation of any kind by a different mode of proceeding, the treatment with alkaline solutions, which we shall presently notice.

Incrusting matter.—The cell wall, besides being lined with the material just described, is also sometimes interpenetrated with another substance, called the *incrusting* or *lignifying matter*, and best seen in the "heart-wood" of trees, which differs from the "sap-wood" by the presence of this substance. It is this which gives the peculiar rigidity to the heart-wood, and which must be removed before the cells can be made pliable; but forming, as it does, a large percentage of such cells, we can easily understand the uneconomical nature of the processes which would attempt to convert hard-wood into useful fibre. The proper solvent for the incrusting matter is caustic alkali. A brown or yellow color is, however, imparted by this reagent, and hence the bleaching action of chlorine must be superadded to remove traces of color caused by small remaining portions of the substance, which would not otherwise affect the useful properties of the fiber. Paper made from wood may frequently be detected by the yellow color caused by the action of alkaline substances.

To describe the properties of the matter in the cork-cells, and in the external coating of plants, would carry us far beyond the limits assigned to this article. It is sufficient to say that these can also be dissolved and removed by alkaline solutions.

Intercellular substance.—There is, however, one substance found in connection with most fibers, whose reactions are of the utmost importance; we refer to what is called the *intercellular substance*, or that which exists between the individual cells, and holds them together. Vegetable anatomists have not yet agreed as to its origin, although the most commonly received opinion is that this substance is derived from the altered remains of the original, or "mother" cells, in which the existing cells have been formed by subdivision. But, although there may be a difference of opinion as to the origin of the intercellular substance, there can be none as to its chemical properties. In general, it is readily attacked by the more powerful chemical agents, which have but little effect, or act but slowly, upon pure cellulose. But the most suitable solvent for this substance, in the case of nearly all fibers likely to prove useful, is an alkaline solution, which we have so often mentioned already as a solvent for nearly all matters found in fiber, except pure cellulose. The nature of the alkaline substance may be varied to suit the circumstances of the case—caustic potash, or soda, their carbonates, the lye from the ashes of plants, lime-water alone, or mixed with potash or soda, as well as other salts with an alkaline reaction, have all been used for the same end. The cost of these articles will, in general, determine which is to be employed, it being remembered, however, that caustic solutions have the most energetic action, and are therefore most economical when rapid and powerful effects are desired.

In every case where it is intended to separate the individual cells, whether for the purpose of imitating cotton by the long cells from certain fibers, such as flax, or for making paper from parts of plants having cells too short for textile purposes, some process embracing a treatment with an alkaline solution must be employed if economy is to be considered. Even in the case of fibrous bundles which are to be merely divided for textile purposes, and not decomposed into the ultimate cells, a treatment with a dilute alkaline solution may be advantageous. The processes of fermentation and of bleaching by chlorine contribute to the same end, but neither of these can be employed alone for that purpose without detriment to the strength of the product.

There is no part of the history of fibers which more strikingly illustrates the general want of knowledge of the subject than that which relates to the very process which we have been considering. A few years ago, the announcement that flax could be converted into a matter resembling cotton, was deemed by many the most remarkable novelty of the age, and there can be no doubt that much money was invested in the proposed new manufacture. But Lady Moira, in the year 1775, treated flax by a method essentially the same as that just referred to, and specimens of the product are still in existence. The process itself, however, was not original with this lady, but dates back at least as far as 1747. So, too, with the similar use of alkaline solutions for the purpose of separating the cells of vegetable substances for paper making. We are informed that the attempt to use this process in the United States, in 1830, was stopped on the ground of the infringement of a patent granted in 1828. But the same thing had been patented in England, in 1801; and it is well known that the same method has been in use in China for centuries, accounts of it having been published by travelers at various times. The published list of English patents for paper making shows at least 50 which depend upon this method, either alone, or combined with bleaching.

Form of the cell.—Having examined the chemical properties of the material of the cell wall, and of the substances connected with it, we next proceed to the consideration of the form of the cell. A great variety of forms may be found even in a single plant, but it is only the elongated cell which is of much importance for fiber, whether it is used in bundles of a number combined together, as in flax, or singly, as in cotton, or broken up, as in paper stuff.

We may best represent to ourselves the form of such cells as they are found in the plant, by imagining a number of cylinders, with more or less pointed ends, placed together so as to "break joint," and then compressed, until the walls of adjoining cells are brought into complete contact, converting each cell from a cylinder into an irregular prism, with a cross section, showing a somewhat polygonal outline. Hairs, such as cotton, the down of the poplar, &c., not belonging to the solid parts of plants, are not always angular in their cross section.

Unequal thickening of the cell wall.—Spiral arrangement.—Vegetable fibers, however, would be very limited in their applications, if each individual cell had a wall of equal thickness throughout; they would then resemble rods, or bundles of rods, which would tend to untwist when twisted, and which, having no hold upon each other, could not easily be submitted to the operation of spinning. In fact, the hairs of many seeds, such as the "silk cotton" of South America, and the "down" or "silk" of many of our native plants, although apparently of great value, from the length of the staple and from their soft and silky character, have proved useless for all ordinary purposes, on account of their imperfectly cylindrical shape and the uniform thickness of their walls.

But, in reality, the growth in thickness of the cellulose is in very few cases quite uniform, the additions which are made on the inside of the cell being confined, mainly, to certain determined lines, or spaces The figures produced by these unequal depositions generally enable us to recognize, under the microscope, each particular kind of fibre, even in the most minute fragments. But the remarkable peculiarity of most vegetable fibers is, that the unequal depositions tend to take a spiral direction, and consequently, when dried and somewhat shrunken, the cells, from rods, become transformed into screws, often, indeed, of very few turns and very fine threads, but still having sufficient inequality of surface to adapt them to the operation of spinning. If the

cross section of the cell is angular, or if, as is sometimes the case, these angles are produced so as to form longitudinal ribs, it can easily be understood that, from the action above described, the result will be a screw of very sharp thread. An instance of this kind has occurred to us, in examining a very remarkable Japanese paper. The fragments, or even entire cells in this paper, were of unusual length, and evidently contributed to the great strength of the paper by their angular and somewhat spiral ribs.

Even in fibers which do not in their ordinary condition show this spiral arrangement, it may often be made manifest by the application of chemical reagents. In the early delineations of fiber, as seen under the microscope, the point of which we are treating seems to have been almost entirely overlooked, but its importance is undoubted, not only as a means of recognizing different kinds of fiber, but as affording a good general idea of the peculiar properties of any one kind.

Pith cells.—We have hitherto treated only of elongated cells; but there are others quite different in shape, being nearly as broad as they are long, or, if elongated, still not pointed. In these, too, the contact of the cells generally produces planes, so that each one has as many facets as it has points of contact with neighboring cells. This kind of tissue has its walls, in most cases, but little thickened, and from the great number of joints has but little strength in any direction. Such cells form the substance which we call "pith," and, for convenience sake, will hereafter be designated as *pith cells.*

The well-known Chinese pith paper is almost the only instance of the application of such a tissue to what might be called fibrous uses. By a spiral cut the pith is unrolled, from the circumference inward, into a sheet, which, by a pressure slightly crushing its cells, is made permanently flat. The extreme fragility of pith paper is a proof of the general inapplicability of this tissue to the purposes of which we are treating. But, though of itself useless, the relations of pith to fibers is of some importance, for in many cases it surrounds and isolates from other structures that which we call fiber, and by the portions of it which remain adhering we may often be able to determine the precise origin of a given specimen. Paper made from the grasses, straw, &c., can always be recognized in this way.

The removal of pith cells is one of the principal objects to be accomplished by fermentation, treatment with alkaline solutions, or the mechanical processes used in the preparation of fibrous material.

Ducts.—There is also another kind of cells, which, contributing little or nothing to the strength of fiber, by their relative position to the elongated cells, materially influence the character of the compound fibers in which they are found. These are the *ducts*, which are formed originally of round or prismatic cells, of some length, placed one over the other, and separated by end partitions, which are not exactly transverse, but slightly inclined from the horizontal. As the cells attain a certain degree of maturity, these partitions become perforated, and each series is then formed into a continuous tube.

The walls of the ducts are variously marked: sometimes the deposit inside is in the form of separate rings, sometimes in that of spirals, and in other cases again pits, arranged in spirals, are found in the otherwise uniformly thickened cell wall. The diameter of the ducts is greater than that of any other form of cell, a matter of no little influence in certain compound fibers.

The characteristic markings of the ducts, and their mode of arrangement, are of service in enabling us to determine the plant from which they are obtained.

GROUPING OF CELLS IN FIBER.

Position of fibers in the plant.—The peculiar mode of grouping of the cells which constitute fiber, and their position in the plant, must next receive our attention.

There are two great divisions of the vegetable kingdom, marked both by internal and external characters, which enable the botanist to decide, with the utmost readiness, upon the proper position of any plant; but as these characters depend upon essential differences in the mode of growth, the two divisions are found to differ widely in the kind of fiber produced, and in its position in the plant.

Position of fiber in endogens.—The first division is formed by what botanists call *endogens*, or inside-growers. This division is best known to us in its herbaceous forms, such as the grasses, including the cereals, sugar-cane, and the common cane; also, the lily, the cat-brier, and, in short, all plants whose leaves have parallel veins. In the south, it is represented by the yucca, or thread-and-needle plant, the agave, or false aloe, and by the palmetto, which, like the palms of the tropics, is furnished with a more or less hard or woody stem. These plants do not form a regular bark, show no rings of annual growth, and do not increase by continued additions on the outside of the stem, as is the case with the woods common in our climate. Such plants show, on a cross section, no lines, but a multitude of dots, without any definite arrangement. In a longitudinal section, it is found that these dots are the sections of long bundles of cells, running lengthwise through the plant. The substance in which the bundles are imbedded is entirely made up of short pith cells, and the whole growth of the fiber, which represents the wood of other plants, is made either by their increase in length or by the introduction of new branches of the bundles among those already formed. As the stems of such plants grow old, not being provided with the means of increasing on their circumference, they become more and more dense from the pressure of the bundles in the interior. In this condition, the trunks of endogens resemble our ordinary woods in solidity, but are not well adapted to furnish fiber, which is generally obtained from the herbaceous stalks and the leaves of plants in this division.

Structure of the fibrous bundles of endogens.—The structure of the fiber of endogens, as developed under the microscope, is worthy of a somewhat extended description. The cross section of the bundles is sometimes nearly circular in outline, more commonly oval, but often rather egg-shaped, or even heart-shaped; and in some cases it is angular, rather than rounded. Near the center of the figure, but on one side of it, large openings will be noticed; these are the sections of the ducts, which we have described above. Very commonly, there are three of these, but the number may vary; the arrangement, however, in most cases, being such as to approach the form of a crescent. Besides the large ducts, there are smaller ones, the peculiarities of whose structure we need not stop to describe. Within the crescent thus formed will be found a group of small cells concerned in the active growth of the plant, and representing those cells which, in ordinary woods, are found between the sap-wood and the bark, and which form the tissue called by botanists the *cambium*. This is generally too delicate in its structure to resist the ordinary treatment to which fibers are subjected, and moreover contains a large portion of nitrogenous or fermentiscible matter. It therefore not only disappears itself in the usual treatment, but also furnishes a material which favors the separation of the remaining cells of the bundle.

Surrounding the different kinds of cell which have been enumerated, we find the true elongated cells, which form the essential constituents of all useful fiber. In some cases these are found in greatest number at the opposite ends of the section, especially when its outline is much elongated; but in a state of maturity, the whole of the bundle is inclosed by thickened cells of this kind.

Although the most common forms of the fibrous bundles of endogens are such as we have just described, there are many deviations from them, some of which have no little influence upon the character of the fiber. In the case of thin leaves of plants in this division, we have found that those bundles which come up to the surface depart from the ordinary mode of structure, being, in general, more ribbon-shaped and round in outline.

Changes produced in the preparation of fiber from endogens.—We have sought in vain for any account of the character of the fiber which ordinary processes produce from such bundles. Our own examination of a large collection of specimens leads to the following views: The ducts, large and small, and the cambium, disappear, while only the elongated cells remain. Two different conditions may then be attained. In one, the hardened, elongated cells form a continuous boundary to the other tissues. In this case the result will be a collapsed tube, nearly round, when the outer cells are much hardened, as in some of the palms, or more or less flattened, when the external rows of cells are softer, and the ducts, and other evanescent tissues on the inside, form a large portion of the section of the bundle. The twist, or wind, of such fibers will depend partly upon the spiral structure in each cell, but still more upon the mode of arrangement of the individual cells in the bundle. In the other case, the exterior row of cells is not sufficiently hardened, or does not form a continuous boundary to the bundle, and then, when the interior portions give way, the groups of elongated cells open into a ribbon, which often has a tendency to separate into two parts.

As a general rule, the round or collapsed tubes are derived from the older portions of the trunks, or thick leaves—the ribbons from the thin leaves of endogenous plants. The respective diameters of such bundles of fiber will have their influence upon the processes to which they may be subjected, and in most cases, from their length, measured by feet and inches, they are best adapted to manufacture of cordage, unless divided by a further treatment into portions, which are, when spun, fitted for the finer textile purposes.