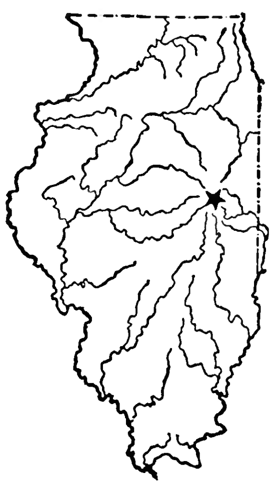
UNIVERSITY OF ILLINOIS

Agricultural Experiment Station

BULLETIN No. 336

QUALITY IN CELERY AS RELATED TO STRUCTURE

By C. B. Sayre



URBANA, ILLINOIS, AUGUST, 1929

CONTENTS

QUALITY IN CELERY AS RELATED TO STRUCTURE[1]

By Charles B. Sayre, Formerly Assistant Chief in Olericulture

Celery to be of good quality must be crisp, tender, and stringless, having a pleasant, sweet, nut-like flavor. Systematic improvement in the quality of celery requires: first, a knowledge of the structural characters of the plant that are correlated with quality or lack of quality; and second, a knowledge of the conditions of temperature, moisture, plant food, maturity, blanching, and varietal differences that affect the structure of celery and its resulting relation to quality. It is the object of this bulletin to present data and information concerning these topics, particularly in regard to a microscopic study of the interior anatomy and structural characters of the celery plant that are correlated with quality.

REVIEW OF LITERATURE

Norton[5*] says that quality in celery is primarily a question of the proportional relationships of the so-called parenchymous tissue to the fibrous tissue. This is determined in part by varietal differences and, within varietal limits, in the main by certain external conditions, such as soil moisture, plant food, rate of growth, light, warmth, pest control, and blanching.

Mills[4*] says that high quality in celery is based on its flavor, crispness, and lack of stringiness. Flavor, he believes, is associated in some way with the chlorophyll in the stalks. It is affected by the rate of blanching and the type of celery, whether of the self-blanching or green type. It is generally conceded that green varieties of celery are of better flavor than varieties of the self-blanching type.

The degree of crispness, he says, is due entirely to the relative water content of the plant. When the cells are turgid the stalk will be crisp, but when the parenchyma cells are not well filled with liquid the stalk will be wilted and lacking in crispness. This lack of crispness may be caused by too high a temperature, too much or too little moisture, too little nitrogen in the fertilizer, checking of growth due to disease, or by too rapid a growth which in turn matures the crop too early in the season, causing pithiness.

Pithiness, Mills believes, is caused by the maturing of the stalk and depends partially at least upon heredity, some strains of celery tending to develop this trouble more than others. A pithy stalk

[1]This bulletin is an abridgment of a thesis accepted in partial fulfillment of the requirements for the master's degree in the Graduate School of the University of Illinois.

cannot be made crisp because the parenchyma cells have collapsed and cannot be filled with water again.

Conditions of storage, Thompson[9*] says, may also affect crispness. Insufficient moisture in storage will cause wilting and lack of crispness. Too high a temperature in storage will cause rapid maturity and result in pithiness.

According to Mills and many other writers, stringiness in celery is due to the development of excessive woody tissue in and around the fibrovascular bundles. Mills claims that in stringy celery these bundles will be found enlarged and the woody cells will extend out into the spaces where the soft-tissue cells should be present, often extending out to the epidermis. Among the causes of this development of excessive woody tissue he mentions strong light and too little light; a check in growth owing to too much moisture, too little fertilizer, or disease; banking too long; or an overrapid growth, causing a woody condition.

The writer cannot agree with Mills' statement that stringiness of celery is due to an enlargement of the fibrovascular bundles, or that woody cells extend out into the spaces where soft tissue should be present. The present paper includes data and microphotographs which the author believes demonstrate that stringiness in celery is due to other structural changes or differences.

White and Sandsten[6*] and also Austin and White[1*] ascribe pithiness in celery to poor seed, especially to seed produced on pithy plants. Their experiments indicate that pithiness is an inherited character and they conclude that a rogueing out of the seed plot of all plants showing pithiness will obviate this undesirable character.

Beattie[2*] says that pithiness in celery may frequently be prevented by proper cultural conditions. Pithiness may be caused by too rank a growth in the seed bed and also by a severe check in growth. Another cause of pithiness, he says, is in leaving the celery in the field too long after it has become blanched. The outer stems in particular tend to become pithy under these conditions.

Flavor in celery is affected by a number of conditions, Beattie says. The strong, rank flavor of celery is caused by the presence of chlorophyll and this is overcome by the blanching process. Blanching destroys the chlorophyll in the stems that are already grown and prevents the formation of chlorophyll in the stems that are produced during the blanching period. Flavor, he adds, is also influenced by the variety. The green types are in general superior to the self-blanching types.

There is a difference of opinion among writers as to the effect of the soil on the quality of the celery it will produce. Watts[10*] says that celery grown on muck soil is inferior in quality to celery grown on upland soil. Thompson[9*] believes that muck soil will produce celery of superior quality to that grown on mineral or upland soils.

He adds that, to be of the best quality, celery must have a continuous growth, and this is more likely to occur on muck soil than on mineral soils owing to the better physical condition and greater water-holding capacity of the muck soils.

STRUCTURE OF THE CELERY PLANT

The celery plant has a large fibrous root system and a very short stem, so short that the leaf petioles appear to arise at the base of the roots. The leaves are compound and have long, thick petioles.

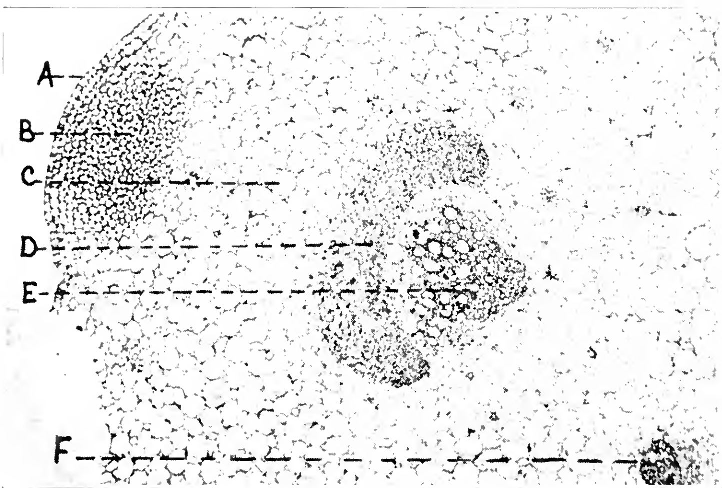


FIG. 1.—CROSS-SECTION OF A PORTION OF CELERY STALK

A, epidermis; B, collenchyma in rib; C, parenchyma; D, phloem; E, xylem (D and E together form the primary fibrovascular bundle); F, secondary fibrovascular bundle.

The leaf petiole is the edible portion of the plant. There are about twenty leaves per plant, some varieties producing more leaves than other varieties.

In cross-section the leaf petiole is somewhat crescent shaped. The exterior side is somewhat ribbed or corrugated and the inner side is smooth. The proportional thickness of the petiole varies with different varieties, some varieties having exceptionally thick leafstalks. A microscopic examination of a section of the celery leafstalk shows that it is composed of a number of different kinds of tissues (Fig. 1).

Entirely surrounding the section, there is an outer layer of tissue, one cell in depth. This is the epidermis and is composed of cells which are somewhat thickened, particularly on the outer side. In addition, a waxy substance called cutin is formed on the outer surface. This forms a thin, waterproof film called the cuticle. The cutinized parts are clearly distinguishable when treated with chloroiodid of zinc.

Inside the epidermis is the collenchyma tissue which occurs as separate strands in the "ribs" or corrugated portion around the exterior side of each stalk; and also as a continuous zone about two cells in depth next to the epidermis. This layer of collenchyma is often deeper on the interior side of each stalk. The collenchyma cells are thick-walled especially at the angles. The depth of this collenchyma layer and the thickness of the cell walls vary with the different varieties of celery.

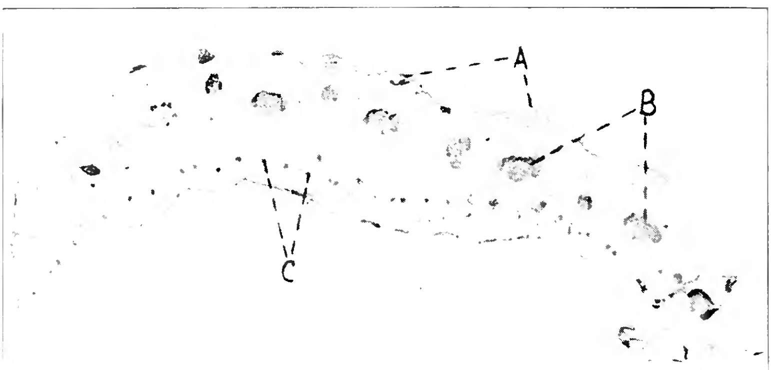


FIG. 2.—CROSS-SECTION OF CELERY PETIOLE SHOWING TYPICAL ARRANGEMENT OF THE PRIMARY AND SECONDARY FIBROVASCULAR BUNDLES

A. collenchyma strands in ribs; B. primary fibrovascular bundles; C. secondary fibrovasular bundles.

The collenchyma strand in a rib is shown in Fig. 1. Arranged as it is near the periphery, the collenchyma embodies the mechanical structure that gives the greatest resistance or strength against bending stresses.

Thin-walled parenchyma tissue lies next to the collenchyma internally and constitutes the greater part of the stalk structure. The cells in this tissue are large, irregular, and thin walled, as shown in Fig. 1. The parenchyma forms the more tender tissue in the stem.

At more or less regular intervals there is a line of bundles of thick-walled cells. These are the fibrovascular bundles. There is one line of rather large bundles which are situated about one-third of the distance in from the exterior side of the stalk. There is likewise a secondary line of a large number of small bundles located parallel to and about one-sixth of the distance in from the interior side of the stalk. A typical arrangement of the primary and secondary bundles is illustrated in Fig. 2, which shows an entire cross-section of a celery petiole.

The fibrovascular bundles consist of three parts, an outer phloem, an inner part or xylem, and a median layer of cambium. The cambium layer is the cell-producing tissue. On the exterior side the cells produced add to the phloem, and on the interior side of the cambium the cells formed add to the xylem.

Since a vascular bundle is in part composed of very delicate cells, it apparently should be protected by some coarser and more resistant tissue, and hence tends to associate itself with mechanical strands. A gutter-shaped sheath of thick-walled cells (the phloem sheath) acts like a splint behind which the delicate parts, particularly the cambium, of the vascular bundle find necessary shelter.

The phloem consists of three elements, the sieve tubes, companion cells, and the phloem parenchyma. The walls of these cells remain cellulose. The cell walls of the phloem sheath are thickened.

In the xylem are found the tracheal vessels and xylem parenchyma. Each tracheal tube is formed by the absorption of the end or transverse walls in a vertical row of cells and, at the same time, there is an enlargement in all dimensions of the cells composing the tube. An unequal thickening and lignification of the vertical walls of these tracheal tubes then occurs. The thick places in the walls strengthen the tube and the thin places make an easy passage for water and materials in solution. The thickened places in the walls are in the form of rings or of a spiral coil. The ring- or hoop-shaped thickening makes what is called an annular tracheal tube. The tubes that have spiral thickening are called spiral tracheal tubes. Both kinds of tracheal tubes can be seen in Fig. 3.

The tracheal tubes are comparatively large in diameter, as shown in Fig. 1. The large, thick-walled, oval-shaped elements in the xylem cross-section are the tracheal tubes.

The row of small secondary vascular bundles seems to be quite similar to the primary vascular bundles, except that the secondary bundles are smaller and the phloem sheath is not so well developed.

Kinds of Skeletal Tissues in Plants

In the larger and more complex plants certain tissues supply strength and rigidity and serve as a skeleton for the plant body as a whole. Four kinds of plant skeletal tissues are recognized. These are: (1) the collenchyma, (2) the bast-fiber tissue, (3) the wood-fiber tissue, and (4) the stone cell or stereid tissue. It is to be expected that one or more of these tissues would be found in the celery plant and would give toughness and stringiness to it. Furthermore, differences in the development of these tissues might be expected to be correlated with differences in quality or lack of quality in different specimens of celery.

According to Stevens[71] the collenchyma is the first kind of skeletal tissue formed in plants. It appears in stems a short distance below the growing apex before the bast and wood fibers and stone cells have begun to be formed. Its chief characteristic is the existence of thickened cell walls at the angles where three or four cells join. In most

FIG. 3.—LONDITUDINAL SECTION OF CELERY SHOWING THE ANNULAR AND SPIRAL TRACHEAL TUBES IN THE DENSER TISSUE OF THE XYLEM

Note the absence of any collenchyma strand at the upper edge. This absence of collenchyma is due to the fact that this section was cut between the ribs.

plants the cell walls remain cellulose thruout. Collenchyma may occur as a continuous zone or in separate strands.

Since the collenchyma is formed where growth is still taking place it must be capable of growing or of stretching. In this elongation of the cells the ends shove past each other and the points become dovetailed and interwoven as shown in Fig. 4. This splicing or interlacing of the cells in the collenchyma increases the strength of this tissue.

Haberlandt[illegible] says, "Organs which are still undergoing elongation must therefore make use of a mechanical tissue which is itself capable of active extension by means of growth. The tissue which satisfies these requirements is *collenchyma*. The fact that collenchyma regularly forms the skeletal system of growing organs does not preclude it from serving as the permanent mechanical tissue in many fully grown herbaceous structures such as petioles." He further states that "while bast fibres and wood fibres perform the task of strengthening fully grown organs, neither of these types of mechanical element is suited to the needs of young organs which are still growing in length." This, of course, would be the case with celery.

The author wishes to call special attention to the foregoing paragraph because it seems that in all the literature in regard to quality

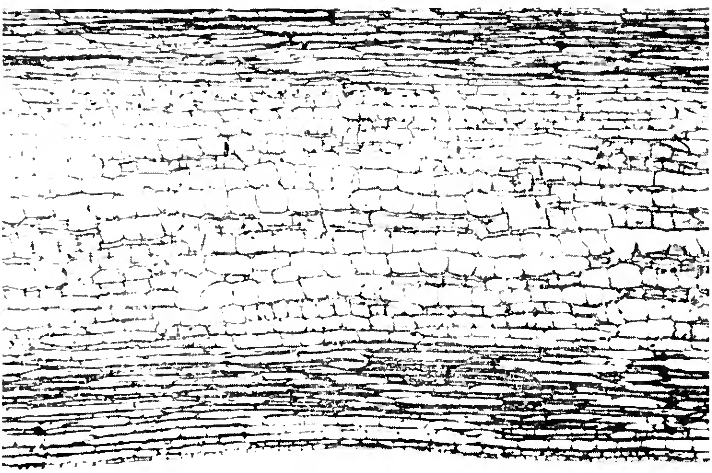


FIG. 4.—PORTION OF LONGITUDINAL SECTION THRU A CELERY RIB

The thick-walled, pointed cell tissue at the bottom is the collenchyma strand in the rib. Note how these cells are pointed and interlaced as contrasted with the thin-walled, square-ended cells of the parenchyma above.

in celery the collenchyma tissue has been overlooked or not taken into consideration. Yet from the standpoint of plant anatomy it seems most logical to expect that the collenchyma would have a very important bearing in the texture and toughness of the celery petiole.

According to Stevens, modifications of the cells in plant skeletal tissues may occur by (1) thickening of the cell walls; (2) chemical alterations of the cell walls by the changing of the old material and depositing of new material; (3) transformations in the physical condition of the cell wall involving changes in its hardness and elasticity.

With a view to determining which, if any, of these three modifications occur or are correlated with differences in quality of celery, very careful microscopic examinations and microchemical tests were made of the structure of celery plants of varying degrees of quality.

An effort was also made to determine what circumstances of culture and environment cause these modifications in the celery plant.

EIGHT VARIETIES TESTED UNDER VARYING CONDITIONS OF MOISTURE AND BLANCHING

This investigation included a study of eight different varieties of celery and a comparison of the effect of different environmental factors on some of these varieties. The different cultural conditions included a series of fertilizer treatments, a comparison of three methods of blanching, and the effect of supplementary irrigation.

Specimens of each variety and from each different condition of environment were carefully studied in an effort to ascertain what factors or conditions affected the quality of the product. Some of the leading commercial varieties were included. The self-blanching varieties were Garrahan's Easy Blanching, a special strain of this popular commercial variety, White Plume, and an ordinary strain of Easy Blanching. Varieties of the green type were Giant Pascal and Emperor. The pink varieties were Sutton's Giant Red, Sutton's Superb Pink, and Rose Ribbed Self-Blanching.

Three different methods of blanching were used in order to determine their effect on the quality of the celery. Both White Plume and Garrahan's Easy Blanching were blanched by each method. The plants were banked with earth, blanched with boards, and with composition paper (R. & D. celery blanching paper).

Celery requires abundant moisture during the growing season. Furthermore, succulence and tenderness in vegetables is often limited by the moisture supply. A comparison was therefore made of the effect of supplementary irrigation in growing each of the eight varieties, in order to determine if extra moisture would improve the quality even tho the celery was grown in a humid region in a season of normal rainfall. The water was applied by means of a Skinner overhead irrigation system. The irrigation was used thruout the growing season whenever it was considered that a little extra water would be beneficial to the plants.

COMPARISON OF VARIOUS SPECIMENS FOR QUALITY

Quality in any vegetable is somewhat indefinite and therefore difficult to measure accurately, especially in the finer degrees. In all of the various state and federal standard grades for celery, stringiness and flavor are left out of consideration. In fact, the only factors of quality that are specified are pithiness and degree of blanching. In order to provide a better basis for comparison of quality the author has assumed certain additional characteristics as essential to good quality. As stated on page 559, celery to be of good quality must be crisp, tender, and stringless, and have a pleasant, sweet, nut-like flavor.

Accordingly, in order to compare the quality of the various specimens of celery, observations were made of the texture, succulence, and flavor of each specimen by an eating test. Texture was recorded as *tender*, *tough*, or *stringy*. Succulence was recorded as *succulent*, or *pithy*. Flavor was reported as *nut-like*, *sweet*, *rank*, or *pungent*.

Specimens were considered tender when the stalk could be broken or bitten thru readily without any undue compression before the tissues would break and without tearing apart in ragged strings. Tough specimens required considerable pressure to break the epidermis and to masticate a portion of the stalk. Stringy specimens were usually tough and had tough, string-like tissues that would tear out readily and were much tougher than the remaining tissues. Specimens were termed pithy if they were of somewhat open texture with air spaces or dry, spongy tissue in the central portion. Crisp celery is both tender and succulent. By succulent is meant especially juicy.

The terms used in describing flavor may be defined as follows: The specimen was termed pungent if it tasted "hot" with a tendency to "bite" the tongue; rank was used when the flavor was strong and grass-like without any sweetness; nut-like was used when the flavor was rich and somewhat like a fine-flavored nut.

To a certain extent, especially in regard to minor differences in flavor, personal preference would be a slight factor in a definite quality rating. To insure greater accuracy in the comparisons, five or more specimens from each lot were sampled and the average impressions recorded. After the plants had been trimmed as for market, three outer stalks were removed and the fourth sampled in particular for the quality tests. In the comparison of varieties the opinions of six advanced students are considered with the author's in the quality rating. In the other lots the rating is based entirely on the opinion of the author.

Comparison of Varieties

Self-Blanching Type. Three varieties or strains of the self-blanching type were included in the comparisons. The rating of each variety may be summed up as follows:

Garrahan's Easy Blanching.—Crisp and tender. In some cases slightly stringy, but the strings are brittle and not tough or tenacious. Flavor sweet and very palatable. This would be classed as a variety of good quality and the best of the three varieties of the self-blanching type.

White Plume.—This variety is tough and stringy, the strings being very tenacious. The flavor is somewhat rank and quite pungent.

Everything considered, this is a variety of very inferior quality. In flavor it was the poorest of any of the varieties tested.

Easy Blanching.—The ordinary strain of Easy Blanching was similar to Garrahan's Easy Blanching but was a little more stringy and less sweet than Garrahan's.

Green Type. The two varieties of the green type that were tested were of excellent quality.

Giant Pascal.—This variety is very crisp and tender. Strings even on the largest stalks are not tough or tenacious but are brittle. The flavor is very palatable, being sweet and somewhat nut-like. This variety seems to meet all of the requirements for high quality.

Emperor.—Emperor is another excellent variety. Like Giant Pascal the stalks are thick and very crisp and tender, without tough strings. The flavor is sweet and somewhat nutty. It is difficult to decide which of these varieties ranks highest in quality. The opinion of six students was that they are both of excellent quality, and the choice was equally divided between the two varieties, but the author has a slight preference for Giant Pascal.

Pink Type. There was a striking contrast in the quality of the three varieties of the pink type that were tested. The two extremes, highest quality and poorest quality, were included in this group.

Sutton's Giant Red.—This variety was very crisp and tender with a total absence of tough strings. The flavor was especially palatable, being sweet, rich, and nut-like. All who sampled this variety agreed that it was of excellent quality in all respects.

Sutton's Superb Pink.—This is another high quality variety, being very crisp and tender, without tough strings, and having an especially palatable, sweet, nut-like flavor. However, in a careful comparison, the Giant Red was ranked as slightly superior in flavor and succulence.

Rose Ribbed Self-Blanching.—In texture and succulence this variety showed the poorest quality of all varieties tested, but in flavor it was superior to White Plume, which was the next poorest variety. Rose Ribbed Self-Blanching is very tough and stringy. The strings are especially tenacious. The flavor is fair, being slightly sweet.

Rating of Eight Varieties. Following is the author's rating of these eight varieties on the basis of quality:

1. Sutton's Giant Red
2. Giant Pascal
3. Emperor
4. Sutton's Superb Pink
5. Garrahan's Easy Blanching
6. Easy Blanching
7. White Plume
8. Rose Ribbed Self-Blanching

There is little choice between the first four varieties. All would be classed as excellent in quality. Garrahan's Easy Blanching would be classed as good in quality, and the last three would be rated poor.

It is worthy of note that the first four varieties are of the slower blanching types, two of them being green varieties and two pink varieties. This is in accordance with the prevailing opinion that the slower blanching type is of somewhat superior quality to the self-blanching type.

Effect of Fertilizer Treatments on Quality. Some Easy Blanching celery that had been grown by another investigator under twenty-two different fertilizer treatments was tested for quality. Five of the best-looking celery plants from each fertilizer plot were carefully tested and compared as to quality. It was hoped to find some indication as to what influence, if any, the different kinds and amounts of plant food might have on the quality of the celery. The cultural conditions were the same on each plot except in regard to the fertilizer treatment, so that any consistent difference in quality could be ascribed to the effect of the plant food. The seedling plants were purchased from a distant grower; they were in transit and arrived during one of the hottest periods of the summer. The soil was dry and the weather very warm and dry when the seedlings were transplanted to the field plots. In addition, there were no facilities for irrigating them.

The above conditions were, of course, exceedingly unfavorable for the best development of the plants. Consequently the entire series was of inferior quality. However, since the plants were available, they were included in the writer's study of quality. No consistent effect upon either texture or flavor could be detected as resulting from any form or amount of plant food used in the experiment. It is the belief of the author, however, that the unfavorable conditions under which this crop was produced affected the crop so adversely that the results were not at all indicative of the effects which plant food may have upon the quality of celery.

Effect of Method of Blanching on Quality. To determine what effect the method of blanching may have on the quality of celery, Garrahan's Easy Blanching and White Plume were subjected to three different methods. Adjacent sections of the same row of each variety were differently blanched. The cultural conditions were identical except for the blanching. All the celery was harvested at the same time. Following is a record of the quality tests of the blanched product:

Garrahan's Easy Blanching.—(1) *Blanched With Boards.* Flavor excellent. Sweet and palatable. Crisp, tender texture. A few strings but they were brittle and not tough and tenacious. (2) *Blanched With R. & D. Blanching Paper.* Flavor rather flat but slightly sweet. Somewhat tough and stringy in texture. (3) *Blanched With Soil.* Flavor very flat and tasteless, not unpalatable but insipid because neither sweet nor pungent. Very inferior in flavor to the plants blanched with boards. Texture slightly tough and stringy.

White Plume.—(1) *Blanched With Boards.* Flavor rank and pungent. Stringy and very tough in texture. (2) *Blanched With R. & D. Blanching Paper.* Flavor slightly rank and pungent. Very tough and stringy. (3) *Blanched With Soil.* Flavor very rank and pungent. Very tough and stringy.

Apparently the method of blanching has no very marked effect on the quality of celery from the standpoint of texture. However, in the case of Garrahan's Easy Blanching, blanching with boards seemed to result in better texture. If the blanching had been allowed to continue for a longer period, it is possible that greater differences in texture would have resulted, tho the entire lot was harvested at the time it was considered to be at its best condition.

The effect of blanching on flavor was rather striking in the case of Garrahan's Easy Blanching. The flavor was decidedly superior in the lot blanched with boards and very inferior in the lot blanched with soil. This is contrary to the general belief that blanching with soil results in superior flavor. However, it should be noted that only the self-blanching type was included in this test and it is possible that the green type might have given different results. It is difficult to explain the insipid flavor in the lot blanched with soil. Perhaps the soil caused a more rapid blanching and consequently a loss of flavor because the process was continued too long.

The prevailing opinion that blanching with soil results in better quality the author believes may not be well founded, differences in quality being due to differences in varieties rather than to methods of blanching. The green varieties are usually blanched with soil while the self-blanching varieties are commonly blanched with boards or blanching paper, and unquestionably the green varieties are of superior quality.

Effect of Supplementary Irrigation on Quality. The following report is a comparison of the effect of supplementary irrigation on the quality of different varieties of celery. The unirrigated lots received only the moisture from the season's rainfall, while the irrigated lots received supplementary overhead irrigation whenever it was thought that additional water might be beneficial to the plants. Otherwise the cultural conditions were the same.

Giant Pascal. Irrigated—flavor excellent; slightly sweet, nutty, and very palatable; crisp texture but slightly stringy tho strings were not tough. *Unirrigated*—flavor excellent; sweet, nutty, and very palatable; crisp, tender, and succulent.

Sutton's Giant Red. Irrigated—flavor excellent; sweet, nutty, and very palatable; very crisp and tender in texture. *Unirrigated*—flavor excellent; sweet, nutty, and very palatable; very crisp, tender, and succulent.

Garrahan's Easy Blanching. Irrigated—flavor excellent; slightly sweet; crisp and slightly stringy tho strings were brittle and not tough. *Unirrigated*—flavor slightly pungent; crisp, but somewhat stringy.

Emperor. Irrigated—flavor excellent; sweet, nutty, and palatable; very crisp and succulent. *Unirrigated*—flavor very good; not quite so sweet as the irrigated lot; crisp and succulent, but slightly stringy tho strings were not tough.

White Plume. Irrigated—flavor rank and pungent; very tough and stringy. *Unirrigated*—flavor slightly pungent, but more palatable than irrigated lot; texture tough and stringy.

Rose Ribbed Self-Blanching. Irrigated—flavor poor; slightly sweet; very tough and very stringy. *Unirrigated*—flavor poor; rather flat but slightly sweet; quite tough and stringy.

Sutton's Superb Pink. Irrigated—flavor excellent; sweet, nutty, and very palatable; crisp and tender in texture. *Unirrigated*—flavor good; slightly sweet and nutty, but not as fine-flavored as the irrigated lot; slightly tough and slightly stringy but strings were not very tough.

From the above results there appears to be a slight advantage in favor of supplementary irrigation. With four of the seven varieties, namely Garrahan's Easy Blanching, Emperor, Rose Ribbed Self-Blanching, and Sutton's Superb Pink, the flavor was superior in the irrigated lot. With one variety, White Plume, the unirrigated lot was superior in flavor. With two varieties, Giant Pascal and Sutton's Giant Red, the flavor seemed equally good on the two plots.

In regard to texture the supplementary irrigation seemed to improve the quality of Garrahan's Easy Blanching and Emperor. However, two other varieties, Giant Pascal and Rose Ribbed Self-Blanching, were of better texture on the unirrigated plots. The other three varieties showed no difference in texture due to the irrigation.

In connection with the above results it should be noted that this celery was grown in a humid region in a season of normal rainfall and that the unirrigated lots made a strong, vigorous growth similar to the plants that were irrigated. The early growth seemed to be a little more rapid on the irrigated lots, but late in the season there was no apparent difference in the amount of growth. Under these conditions striking contrasts in quality from the additional irrigation could scarcely be expected.

LABORATORY TECHNIC

In order to make microscopic examinations of the various specimens of celery, samples were taken and the material prepared in the following manner. An effort was made to select typical specimens of each lot in the manner previously described. After the celery was trimmed as for market, three outer leaves were removed and the fourth one taken for sampling. A section about one inch long was cut from this leaf petiole beginning one inch above the base.

Each segment for examination was first labeled and placed in a fixing solution. For this purpose a saturated solution of picric acid in 70-percent alcohol was used. Picric acid was chosen because of its great penetration and because it would fix and preserve the entire section without unduly hardening the tissues. Furthermore tissues fixed in picric acid can, after the washing out of the acid, be perfectly stained with any stain.

The picric acid was then washed out by soaking the material in numerous alcohol baths. After the picric acid was entirely washed out, the alcohol was removed by gradually introducing choloroform and then paraffin, and the material was imbedded in paraffin molds.

Using a microtome, sections 9 microns in thickness were made of each specimen. Cross-sections were made of each sample, and longitudinal sections were also made of specimens that showed outstanding differences in the quality tests. These sections were mounted on slides.

At first a triple stain was tried consisting of safrinin, gentian violet, and orange G, but this combination of stains did not bring out satisfactory contrasts in the coloring of the different tissues. It was found that staining the sections first in safrinin and then in Delafield's haematoxylin colored the sections very satisfactorily. All the sections were thereafter stained by that process.

For the microchemical tests that were made to determine the composition of the cell walls, sections were cut 30 microns in thickness. They were then dropped into xylol to remove the paraffin. After the paraffin had been dissolved, the sections were placed in 95-percent alcohol.

Sections to be tested with phloroglucin were then placed in alcohol in which a trace of phloroglucin had been dissolved. After ten minutes in this solution the sections were transferred to a drop of water on a slide and covered with a cover glass. A drop of hydrochloric acid was then applied at the edge of the cover glass, and the effect was observed thru a microscope. As the acid came in contact with lignified tissue, this part became a bright violet-red, while the cellulose was not stained.

Sections to be tested with chloroiodid of zinc were taken from the alcohol bath previously mentioned and were placed in water. From this the sections were placed in a few drops of chloroiodid of zinc on a slide and covered with a cover glass. The resulting staining by the chloroiodid of zinc was then observed thru a microscope. With this stain, cellulose walls are colored violet, lignified membranes are stained brown, and cutinized membranes are colored yellow.

RESULTS OF MICROSCOPIC EXAMINATIONS

After being stained and mounted as described, specimens of each sample of celery that was tested for quality were carefully examined under a microscope to determine what differences, if any, in the structure of the plant were correlated with differences in quality. First, in order to become familiar with the character of the different tissues and cell structures composing the celery stalk, a thoro study was made of several longitudinal and cross-sections. A general description of this internal structure is given on pages 561 to 563.

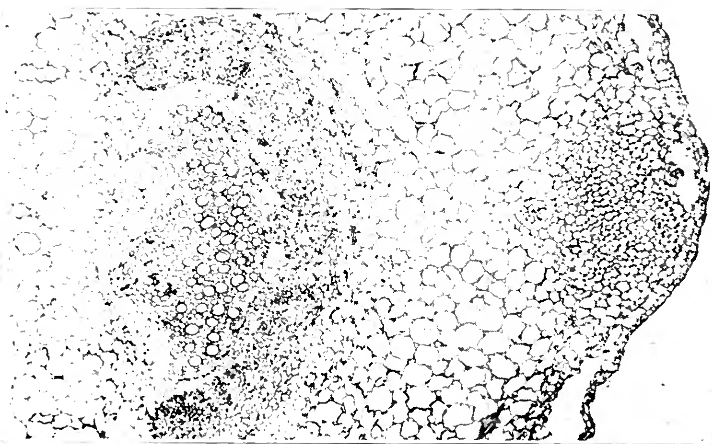


FIG. 5.—A TENDER SPECIMEN OF SUTTON'S SUPERB PINK

Note the unbroken collenchyma strand in the rib and the large fibrovascular bundle.

After this preliminary study was completed, a detailed study was made of the structure of specimens that had shown striking differences in the quality tests. It was thought that any differences in the morphology of the plants that might be correlated with differences in quality would be most readily discovered by the examination of markedly contrasting specimens.

Comparison of Bundles, Xylem, and Phloem. First, the number of fibrovascular bundles in tender specimens was compared with the number of these bundles in tough specimens, then the size of the bundles was compared in each case; but there seemed to be no differences either in the number or in the size of the bundles that were consistently correlated with either phase of quality. This is illustrated by comparing Fig. 5, a microphotograph of a very tender specimen having extremely large fibrovascular bundles, and Fig. 6, a very tough, stringy specimen having much smaller fibrovascular bundles. The magnification is the same in each of these photographs, so that the proportional size of the bundles is as shown.

Next an examination was made of the size of the xylem, and a count was even made of the number of large tracheal vessels in the xylem of specimens of different quality. Again the results were negative. The structure of the phloem sheath was then carefully examined in regard to the size of the phloem, relative size and thickness of these cell walls, and shape of the phloem sheath, that is, whether it extended well down around the xylem in a horseshoe shape or

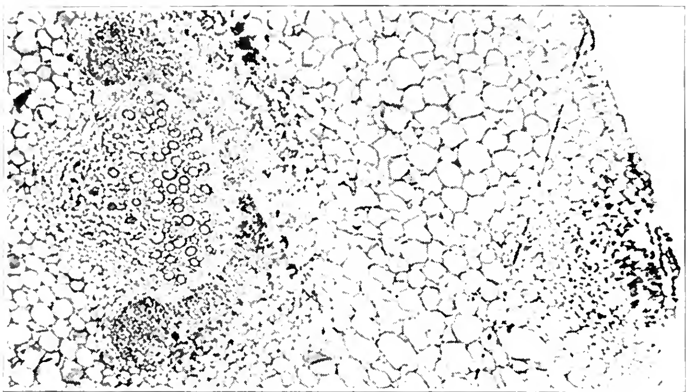


FIG. 6.—TOUGH, STRINGY SPECIMEN OF ROSE RIBBED SELF-BLANCHING
Note the badly broken cells in the collenchyma and the small size of the fibrovascular bundle.

not. But in all these phases of the plant structure, the differences noted did not seem to be correlated with differences in quality. Altho considerable variation was observed in the structure of different specimens, yet similar variations of the characters mentioned were found in specimens markedly different in quality.

Toughness Not Due to Separation of Bundles From Other Tissue. While seeking some other connection between the structure of the fibrovascular bundles and toughness of the plant, it was observed that in some of the tough specimens the tissue surrounding the bundles was torn away from the bundle tissue, and that in some of the tender specimens the tissue surrounding the bundles was not sharply differentiated or torn away but seemed to blend into the tissue of the bundles. This suggested the theory that there might be a difference in the hardness of the cell walls of the different tissues and that the greater the difference in relative hardness of the different tissues the more noticeable would be the harder tissues when one was eating the celery. Hence such specimens would be judged as tough or stringy, and therefore poorer in quality, because the contrast in hardness of the different tissues would emphasize the tougher tissue. However, after examining more sections, it was found that some tender specimens showed a distinct separation of the fibrovascular bundles from the surrounding tissue, and that in some tough specimens the bundle tissue seemed to blend into the surrounding tissue.

Another negative result that should be mentioned is that no bast fibers, wood fibers, or stone-cell tissues were found in any of the sec-

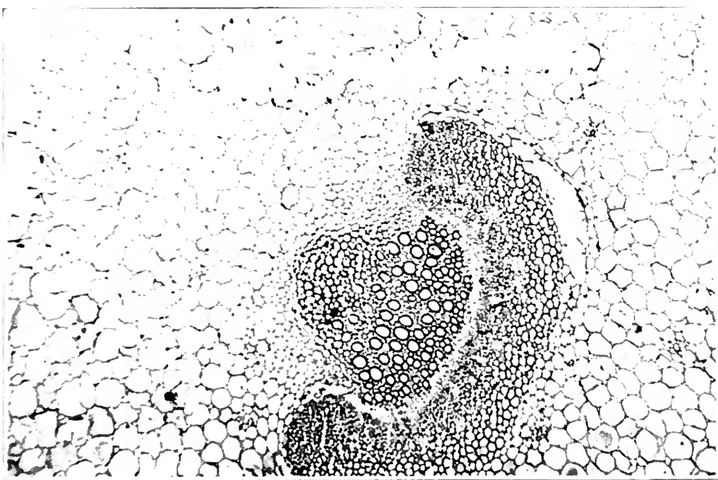


FIG. 7.—A PITHY SAMPLE OF GARRAHAN'S EASY BLANCHING
Note the open texture due to the rupture of large areas of parenchyma cells.

tions. This eliminates these three of the four plant skeletal tissues from further consideration in relation to quality of celery.

Relation of Collenchyma to Quality. Having eliminated the above factors, attention was then concentrated on the one remaining kind of plant skeletal tissue, the collenchyma. It was observed that this tissue was most prominent in the ribs and that each rib was essentially a large strand of collenchyma tissue. However, it was noticed that the collenchyma cells were most clear and distinct in the cross-sections of the tender specimens, as shown in Figs. 5 and 9. This seemed to be another negative factor until it was noticed that the reason the collenchyma was less distinct in tough, stringy specimens was that in those specimens the collenchyma cells were badly broken, making this tissue somewhat confused and indistinct as shown in Figs. 6 and 8. The broken cells would indicate greater hardness of this tissue, for extremely hard tissues invariably have a tendency to break or tear when they are being sectioned instead of showing a clean cut. This suggested that there probably was a difference in the hardness of the cell walls of the collenchyma of different specimens and that the hardening of this

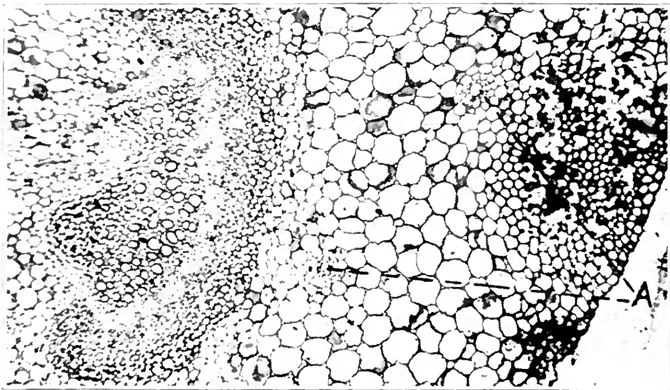


FIG. 8.—TOUGH, STRINGY SAMPLE OF WHITE PLUME

Note the broken collenchyma cells, and also the glands or oil ducts (A).

tissue would cause greater toughness and stringiness. A careful examination of all the specimens seemed to substantiate this theory, as shown in the following detailed description of the microscopic appearance of various sections.

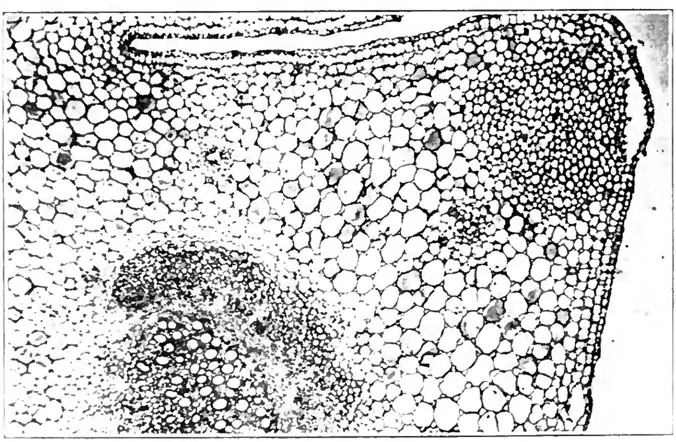


FIG. 9.—A TENDER INNER STALK OF WHITE PLUME

Note the clear-cut, unbroken collenchyma in rib. Compare this with the sample shown in Fig. 8.

Examination of pithy specimens seemed to show a direct correlation between pithiness and open spaces that were due to the rupture or collapse of parenchyma (Fig. 7). Apparently large areas of parenchyma cells are torn apart or ruptured, leaving open spaces in the interior of the stalk and thus causing pithiness.

Toughness Not Associated With Oil Ducts. In most of the specimens a peculiar cell structure was found which was not definitely identified. This has the appearance of a duct or gland, and it is thought that these structures may be oil glands or oil ducts. If this is the case, they probably have some relation to flavor, but this connection was not established. These structures are marked "gland or oil duct" in Figs. 8 and 12 and may also be seen in the other pictures. These glands were found in both tender and tough specimens and therefore did not seem to have any connection with toughness of the plant.

Detailed Study of Selected Specimens. In the following detailed description of the microscopic appearance of some of the various specimens, a few individuals of contrasting quality are described first and the remaining ones are given in numerical order.

No. 42. Rose Ribbed Self-Blanching From Unirrigated Plot. Very tough and stringy. Flavor flat. Eleven primary fibrovascular bundles. Bundles somewhat small. The phloem sheath extends well down around the xylem and is composed of small, thick-walled cells. Large tracheal vessels in the xylem. Parenchyma cells large, irregular in shape, and thin walled. Inner row of 25 small secondary fibrovascular bundles. Collenchyma strands at each rib show cells badly broken.

A portion of the cross-section of this specimen is shown in Fig. 6 and a longitudinal section in Fig. 3. The latter view shows both spiral and annular tracheal vessels.

No. 43. Sutton's Superb Pink From Irrigated Plot. Very crisp and tender, with excellent sweet, nutty flavor. Thirteen primary fibrovascular bundles, which are comparatively large. Thirty-eight small secondary bundles in a row near the inner edge. Large number (about 68) large tracheal vessels in xylem. Large phloem sheath, somewhat bow shaped and composed of small dense cells. Parenchyma cells are large, irregular, and thin walled. Large collenchyma strand in rib. Collenchyma cells show distinct thickening at corners and cut cleanly without breaking. Epidermis distinct and clearly shows thickening of cells on outer side (the cuticle).

A cross-section view of this specimen is shown in Fig. 5.

No. 28. White Plume Blanched With Boards. Very tough and stringy. Flavor rank and pungent. Thirteen primary fibrovascular bundles of medium size. Forty-nine small secondary bundles in a row near the inner edge. Medium number (average 40) large tracheal vessels in the xylem. Large phloem sheath, somewhat bow shaped, and composed of small thick-walled cells. Strand of collenchyma tissue in each rib and also a layer of collenchyma about two cells wide just below the epidermis on the inner surface of the stalk. The collenchyma cells are thick walled and badly broken, particularly in the strands of the ribs, indicating that they must be especially hard. Just below the collenchyma strand in each rib there is a very prominent oil duct or gland. Similar glands are scattered thru the parenchyma. The parenchyma has unusually large cells which are irregular in shape and thin walled (Fig. 8).

No. 31. Inner Stalks of White Plume. Tender, with strings present but brittle and not tough. Flavor mildly rank. Nine primary bundles which are medium in size. Large tracheal vessels in the xylem, but only about three-fourths as many of the tracheal vessels as in No. 28, an outer stalk. The phloem sheath is large and forms a semicircle around the xylem. The phloem cells are small and thick walled. The parenchyma cells are large, irregular in shape, and thin walled. There is a very clear-cut collenchyma strand in each rib. The collenchyma cells show a distinct thickening at the angles and cut cleanly without breaking or tearing, which indicates that they are not hard.

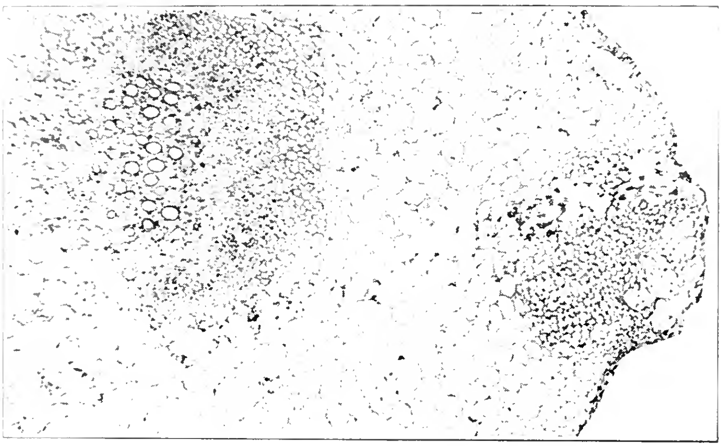


FIG. 10.—NO. 2, A TOUGH, STRINGY SPECIMEN OF EASY BLANCHING

Note the small fibrovascular bundle and the shading off of the xylem, also the badly broken collenchyma.

Directly below the collenchyma strand in each rib is a distinct gland or oil duct. Similar glands are scattered thru the parenchyma (Fig. 9).

No. 45. Pithy Specimen of Garrahan's Easy Blanching. Not very tough or stringy, but stalk is pithy and spongy and entirely lacking in crispness. Flavor slightly sweet, but rather flat. The microscopic examination showed 12 large primary fibrovascular bundles and 33 small secondary bundles. The bundles were clearly differentiated from the surrounding parenchyma. The cell walls of both the xylem and phloem tissue seem strikingly thicker than the cell walls of the surrounding parenchyma which make the bundles stand out so clearly. There is a medium number of large tracheal vessels in the xylem. The phloem sheath is large and forms a distinct semicircle around the xylem. The parenchyma cells are very large and thin walled. There are large open spaces in the parenchyma tissue and a distinct collenchyma strand in each rib. The collenchyma cells are thickened at the angles and some of these cells are broken but they are mostly intact, indicating that this tissue is only slightly hardened. A little below each collenchyma strand is a distinct gland, and other glands are scattered thru the parenchyma (Fig. 7).

Longitudinal sections of this specimen show that the large open spaces in the parenchyma extend for considerable distances lengthwise of the stalk.

No. 2. Easy Blanching. Tough and stringy. Slightly sweet flavor. The microscopic examination reveals 9 primary fibrovascular bundles and 28 small secondary bundles. The primary bundles are comparatively small. The tracheal vessels in the xylem are of large size, but comparatively few in number. The xylem seems to blend into the adjoining parenchyma. The phloem sheath is wide, does not extend well around the xylem, but forms an arc on the outer side. The phloem cells are small and thick walled. The parenchyma cells are large and thin walled. Scattered thru the parenchyma are distinct glands or oil ducts. There is a large collenchyma strand in each rib. The collenchyma cells are small and thick walled, especially at the angles. Much of this tissue is broken and torn, indicating that it is of too hard a texture to cut readily (Fig. 10).

A longitudinal section of this specimen shows that the collenchyma cells are long and pointed with a spliced or interlaced arrangement. The parenchyma cells are somewhat square or rectangular, and the phloem cells are long with rather square ends. Most of the tracheal vessels show annular rings and a few have spiral reinforcement.

No. 5. Easy Blanching. Very tough and stringy. Slightly sweet flavor. Nine primary fibrovascular bundles and 28 secondary bundles. There is a collenchyma strand in each rib, composed of thick-walled cells which are badly broken, indicating very hard texture.

No. 6. Easy Blanching. Very tough and stringy. Slightly sweet flavor. Twenty-one primary fibrovascular bundles, medium in size. The phloem sheath is crescent shaped and composed of very thick-walled small cells which are distinctly differentiated from the parenchyma. There are about 40 large tracheal vessels in the xylem. The collenchyma in the ribs is very badly broken, indicating hard texture. There is also a layer of collenchyma about three cells deep just inside the epidermis on the concave or inner side of the stalk.

No. 9. Easy Blanching. Slightly stringy, but fairly crisp and tender. Slightly sweet flavor. Eighteen primary fibrovascular bundles medium in size. Twenty-nine secondary bundles. Phloem sheath wide and crescent shaped and composed of small, thick-walled cells. Medium number of large tracheal vessels in xylem. Several oil glands scattered thru parenchyma. Distinct collenchyma strand in each rib. The collenchyma cells are distinctly thickened at the corners. The clearness of the section thru this tissue and comparatively few broken collenchyma cells indicates that the collenchyma was not as hard in texture as in No. 6. There is a distinct collenchyma layer about two cells deep just beneath the epidermis on the inner side.

No. 15. Easy Blanching. Slightly stringy, but a trifle tender and somewhat pithy. Sweet flavor. Fourteen primary fibrovascular bundles, rather large in size. Many large tracheal tubes in xylem. Phloem sheath crescent shaped and composed of very thick-walled, small cells. Parenchyma cells large, irregular, and thin walled with many ruptured, making open spaces in this tissue. Distinct glands scattered thru the parenchyma. Large collenchyma strand in each rib. Collenchyma cells distinctly thickened at corners, and a few of them broken (Fig. 11).

No. 16. Easy Blanching. Very tough and stringy. Rank, pungent flavor. Twenty-one large-sized primary fibrovascular bundles and 46 secondary bundles. Large number of tracheal vessels in xylem. Phloem sheath rather wide and horseshoe shaped, extending well down around xylem. Parenchyma cells large, irregular, and thin walled. Several glands scattered thru the parenchyma. Collenchyma strand in each rib composed of thick-walled cells badly broken, indicating very hard texture.

No. 19. Easy Blanching. Somewhat tough and stringy. Slightly sweet flavor. Seventeen rather small primary fibrovascular bundles and 30 secondary bundles. All tissues similar to those described in No. 16 except that the oil ducts seem more abundant and the collenchyma tissue is not quite so badly

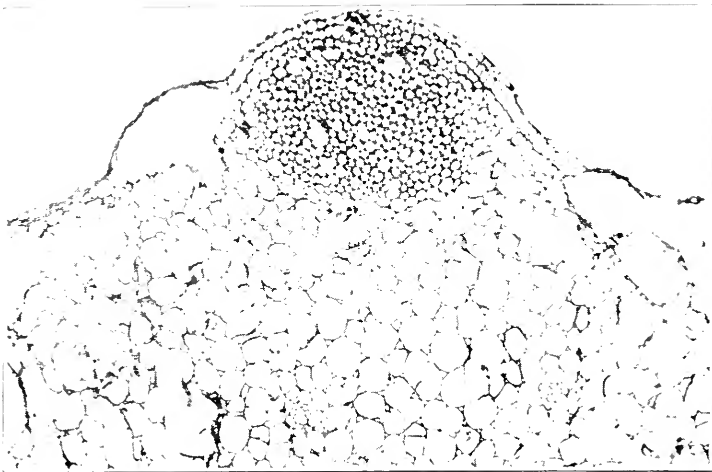


FIG. 11.—No. 15. A SOMEWHAT PITHY SPECIMEN OF EASY BLANCHING SHOWING MANY RUPTURED PARENCHYMA CELLS

broken and torn, indicating that while it is quite hard in texture it may not have been so hard as in No. 16 (Fig. 12).

No. 20. Easy Blanching. Very tough and stringy. Slightly sweet flavor. Nineteen primary fibrovascular bundles, quite small in size. Tracheal vessels in

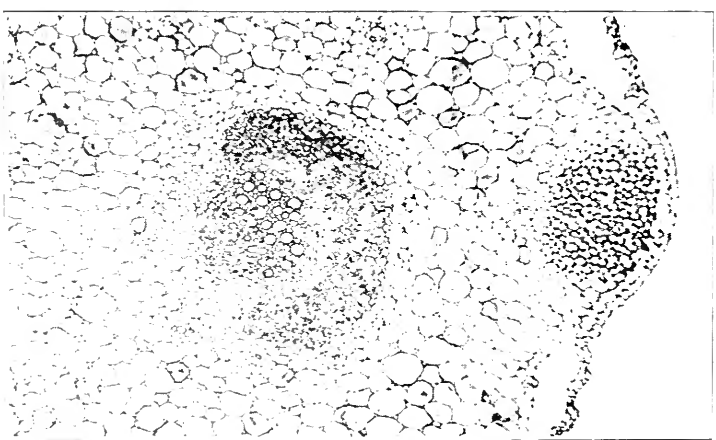


FIG. 12.—No. 19, EASY BLANCHING, SHOWING A LARGE NUMBER OF OIL GLANDS OR DUCTS SIMILAR TO THOSE INDICATED IN FIG. 8

xylem large in size but few in number (24). Phloem sheath forms wide semicircle around xylem. Bundles clearly differentiated from surrounding tissue because of their greater density. Parenchyma cells large, irregular, and thin walled.

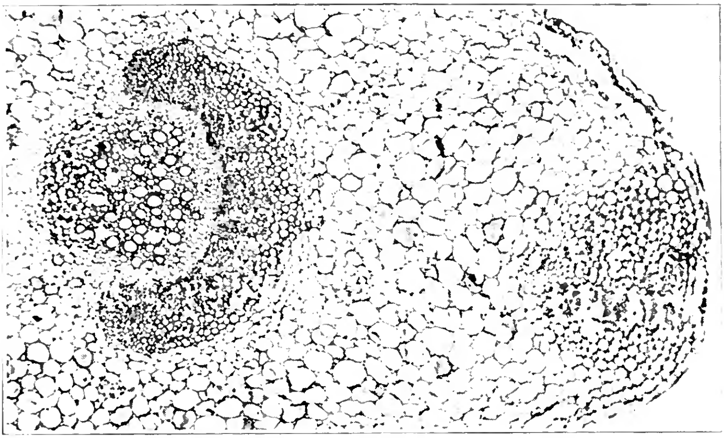


FIG. 13.—A VERY TOUGH AND STRINGY SPECIMEN OF EASY BLANCHING, WITH SMALL FIBROVASCULAR BUNDLES

An unusually large number of glands scattered thru the parenchyma. Dense collenchyma strand in each rib, this tissue being badly broken, the cells breaking in sharp angles as tho very hard in texture.

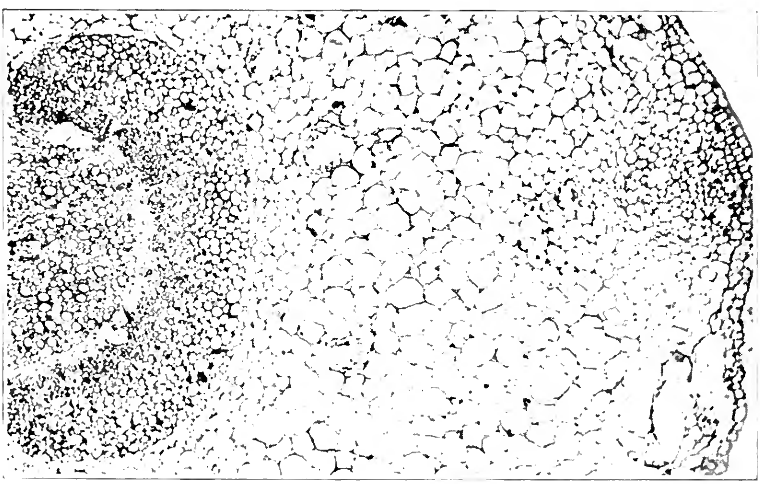


FIG. 14.—A SLIGHTLY STRINGY, BUT FAIRLY TENDER SPECIMEN OF GARRAHAN'S EASY BLANCHING

This sample shows very large fibrovascular bundles at left-hand side and small collenchyma strand at upper right-hand side.

No. 22. Easy Blanching. Very tough and stringy. Rank, pungent flavor. Nineteen primary fibrovascular bundles, somewhat small in size. Medium number of tracheal vessels in xylem. Phloem sheath forms wide semicircle around the xylem. Phloem cells small and thick walled. Numerous glands scattered thru the parenchyma. Collenchyma tissue considerably torn and broken, indicating hard texture of cell walls. Also a layer of collenchyma about two cells deep just below inner epidermis (Fig. 13).

No. 23. Garrahan's Easy Blanching Blanched With Boards. Slightly stringy, but strings are not tough. Fairly crisp. Flavor sweet. Fifteen primary fibrovascular bundles, large in size. Thirty-seven secondary bundles. Xylem rather large with numerous (about 70) large tracheal vessels. Phloem sheath in semicircle around the xylem. The outer cells in this sheath are large and tend to blend into surrounding parenchyma. Parenchyma cells very large, irregular, and thin walled. A few glands scattered thru the parenchyma. The collenchyma strand in each rib is not large. The collenychma cells are rather large. Very few are broken, indicating that this tissue is not especially hard in texture (Fig. 14).

No. 24. Outer Stalk of Garrahan's Easy Blanching Blanched With Boards. Quite stringy and tough. Flavor sweet, slightly rank. Fourteen large-size primary fibrovascular bundles and 27 secondary bundles. Xylem large with many large tracheal vessels. Wide phloem sheath in semicircle around xylem. Small, thick-walled cells on inner edge of sheath grading into larger cells on outer edge. A few glands scattered thru the parenchyma. Rather small collenchyma strand in each rib. Most of the collenchyma tissue broken and torn, indicating hard texture of cell walls. Distinct collenchyma layer about four cells deep just below epidermis on concave or inner side of stalk.

No. 25. Inner Stalk From Same Plant as No. 24. Crisp and tender. Sweet flavor. Eleven primary fibrovascular bundles, quite small in size. Small number of large tracheal vessels in xylem. Phloem sheath composed of dense, small cells forming an arc on the outer side of the xylem but not extending far around the xylem. Parenchyma cells large, irregular, and thin walled. Numerous glands scattered thru the parenchyma. Large, distinct collenchyma strand in each rib. The collenchyma cells are small and thickened at the angles. The entire collenchyma tissue at every rib was intact, showing that it cut readily and therefore the texture of these cells was not hard.

Fig. 1 shows a portion of the cross-section of this specimen. A longitudinal section showed the collenchyma cells to be spindle shaped and spliced or interlocked.

No. 30. White Plume Blanched With R. & D. Paper. Very tough and stringy. Flavor rank and pungent. Fifteen large primary fibrovascular bundles and 24 secondary bundles. Xylem large with numerous (65) large tracheal vessels. Phloem sheath composed of small, thick-walled cells, and extends well around the xylem in a horseshoe shape. Collenchyma strand in each rib very badly broken, cells very thick walled and broken in sharp fragments, indicating hard texture. Layer of collenchyma about three cells deep next to inner epidermis.

A longitudinal section of this specimen showed that the collenchyma cells were spindle shaped but badly broken. Many annular and a few spiral tracheal vessels were found.

No. 32. Giant Pascal From Irrigated Plot. Crisp texture but slightly stringy, tho strings were not tough. Flavor sweet and nutty. Thirteen primary fibrovascular bundles, medium in size. Twenty-seven secondary bundles. Xylem rather large, with comparatively few (about 36) large tracheal vessels. Phloem

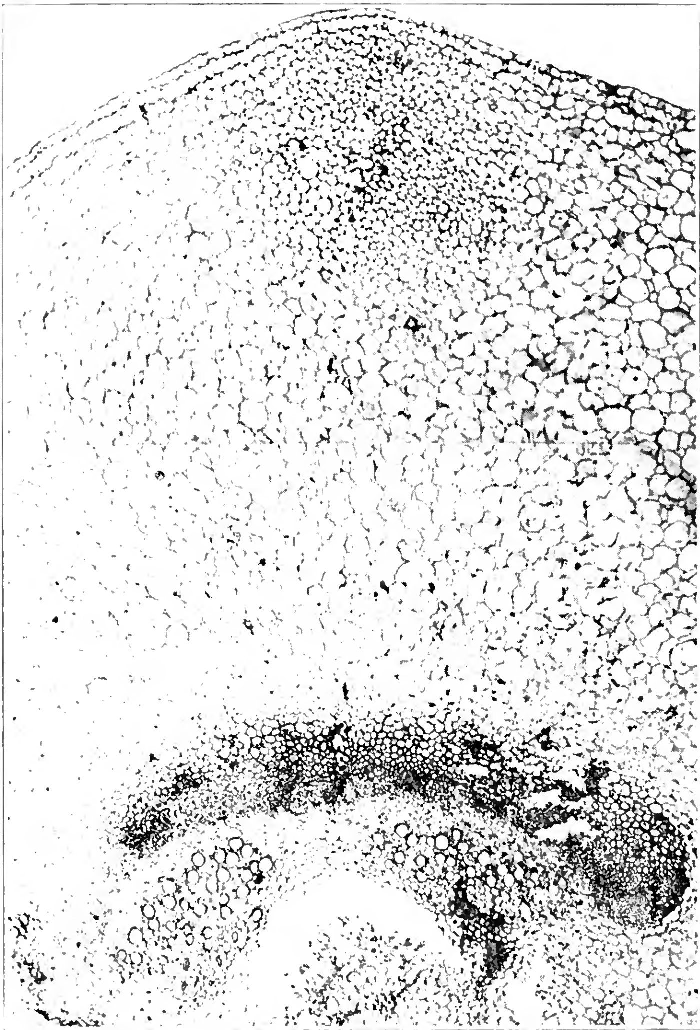


FIG. 15.—NO. 35, SUTTON'S GIANT RED

Note the large fibrovascular bundle and extensive but unbroken collenchyma strand. The large size of the bundle made it necessary to take two photographs in order to show both the fibrovascular bundle and the collenchyma.

sheath wide and crescent shaped. Bundles seem to blend into the surrounding parenchyma. Parenchyma cells very large and thin walled. Comparatively few glands scattered thru the parenchyma. Distinct collenchyma layer next to epidermis on concave side. Collenchyma strand in each rib fairly intact, tho some cells were broken, indicating only slightly hard texture.

No. 33. Giant Pascal. Inner stalks from No. 32. Very crisp and tender. Sweet, nutty, flavor. Nineteen small primary fibrovascular bundles. No inner row of secondary bundles. Very few (about 15) large tracheal vessels in xylem. Phloem sheath crescent shaped and quite wide. Bundle cells much thicker walled and therefore distinctly differentiated from surrounding parenchyma. The bundles were much smaller than the bundles in No. 32. Very clear-cut collenchyma strand in each rib. These cells show distinct thickening at the angles but cut without breaking or tearing, indicating that the cell walls were not hardened. Narrow layer of collenchyma next to epidermis on concave side. A longitudinal section of this specimen (Fig. 4) shows that the collenchyma cells are spindle shaped and interlocked while the parenchyma cells are somewhat square. The cells of the phloem sheath are very long and somewhat oblong in shape. The tracheal tubes show very distinct annular rings.

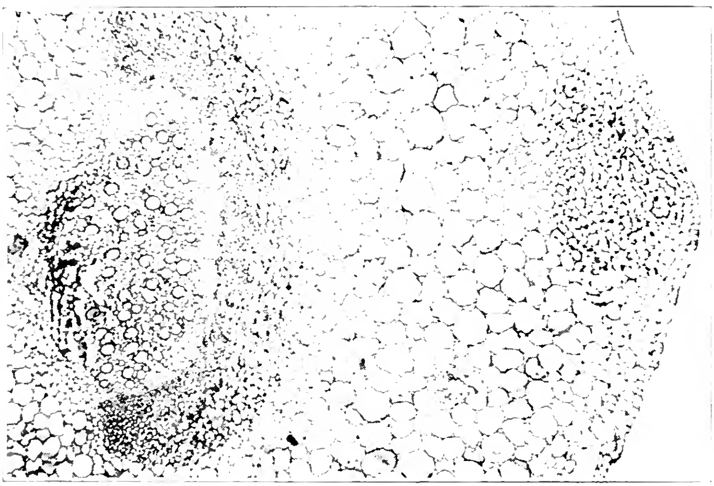


FIG. 16.—EMPEROR CELERY STALK (NO. 39), A CRISP, SUCCULENT SPECIMEN WITH LARGE FIBROVASCULAR BUNDLES

No. 35. Sutton's Giant Red From Unirrigated Plot. Very crisp, tender, and succulent. Sweet, nutty flavor. Eleven very large primary fibrovascular bundles. Thirty-five secondary bundles. Altho the bundles are larger than those found in any previous specimen, they seem to blend into the surrounding parenchyma. Very numerous (about 90) large tracheal vessels in xylem. Phloem sheath bow shaped and narrow in proportion to length. Parenchyma cells large and thin walled. Glands or oil ducts scattered thru the parenchyma. Rather extensive collenchyma strand in each rib, comparatively thin-walled cells for collenchyma, showing distinct reinforcement at angles. The collenchyma strands mostly intact with very few cells broken, indicating that texture is not hard (Fig. 15).

No. 36. Sutton's Giant Red From Irrigated Plot. Very crisp and tender. Sweet, nutty flavor. Twelve large primary fibrovascular bundles and 28 secondary bundles. All tissues very similar to No. 35. Longitudinal section shows both annular and spiral tracheal vessels; also showed collenchyma cells spindle shaped and spliced or interlocked.

No. 39. Emperor From Unirrigated Plot. Crisp and succulent but slightly stringy, tho strings are not tough. Sweet flavor. Thirteen large primary fibrovascular bundles, and 22 secondary bundles. Medium number of large tracheal vessels in xylem. Phloem sheath bow shaped and rather narrow. Parenchyma cells very large and thin walled. Numerous glands scattered thru the parenchyma. Rather small collenchyma strand in each rib. Comparatively large collenchyma cells with distinctly thickened corners. Cells mostly intact but somewhat broken, indicating a hardened texture (Fig. 16).

Microchemical Tests

To determine the composition of the cell walls in the various tissues, a number of sections were treated with phloroglucin and with chloroiodid of zinc, as described on page 572. The following specimens were tested by these methods: Nos. 2, 24, 25, 29, 35, 36, 38, 39, 40, 42, 43, 44, and 45. This assortment embraced all varieties and included both tough specimens and tender ones, and inner and outer stalks. Both longitudinal and cross-sections were tested. The results were identical in each case. Consequently one description will suffice for all.

There were only two kinds of tissues that showed lignification; namely, the tracheal vessels and the oil glands or ducts. In all specimens only these elements were lignified and the inner tender stalks showed the same lignification as the outer tough stalks. This was similar in all varieties. There were no additional lignified elements in the tough, stringy specimens. The spiral and annular reinforcement in the tracheal vessels in all specimens seemed particularly lignified. The tracheal tubes in the secondary bundles showed the same lignification as the tracheal tubes in the primary bundles.

Neither chemical test showed any trace of lignin in the collenchyma. Therefore, there was no lignification in the ribs of the celery. In the tests with chloroiodid of zinc the collenchyma, parenchyma, and phloem and the other xylem elements except the tracheal tubes all stained clear violet, indicating pure cellulose walls. The outer side of the epidermal cells (the cuticle) stained clear yellow, indicating that it was cutinized.

SUMMARY AND CONCLUSIONS

This investigation resulted in some conclusive evidence in regard to certain changes in the morphology of the celery plant that are correlated with quality. The choice of the horticultural variety is of great importance in producing high-quality celery, and the environment under which it is grown may cause modifications in the structure of the plant which affect its quality. Haberlandt[38] says, "Generally speaking, both the qualitative and the quantitative development of the mechanical system are included among the hereditary characters of the species. Nevertheless, a certain amount of direct accommodation to external conditions on the part of the *mechanical system* may take place during the life of the individual plant."

In determining the nature of the changes in the mechanical system which are correlated with toughness and stringiness in celery, some negative results seem especially significant, particularly in regard to the relation of the fibrovascular bundles to stringiness.

1. Contrary to popular belief and to the opinion of some writers, this investigation seemed to show conclusively that the size of the fibrovascular bundles in celery is not a factor in causing stringiness. One of the most tender varieties, Sutton's Giant Red, had unusually large fibrovascular bundles (Fig. 15). Another tender variety, Giant pascal, had medium-sized bundles. On the other hand, Rose Ribbed Self-Blanching, a very tough, stringy variety, had medium-sized bundles (Fig. 6). Another tough variety, White Plume, also had medium-sized bundles (Fig. 8). Apparently the size of the fibrovascular bundles is rather constant within a variety, but varies between varieties, and large bundles are not correlated with tougher or stringier varieties.

The fibrovascular bundles are smaller in the smaller inner stalks on the same plant than in the large outer stalks but are in proportion to the entire size of the stalk.

The number of fibrovascular bundles in a stalk likewise seems to have no relation to stringiness or toughness. There is a great variation in the number in different stalks of the same or of different varieties and even in different stalks from the same plant, but there seems to be no increase in the number of bundles in tough, stringy specimens as compared with tender specimens.

2. No bast fibers were found in any specimens. Stringiness, therefore, cannot be attributed to the presence of this tissue. The elements called glands or oil ducts, which were found scattered thru the parenchyma and which were lignified, seemed to have no relation to toughness or stringiness. Probably these elements, if they are oil ducts, have some relation to flavor, but there seemed to be no correlation between the number of these ducts and the flavor of the specimen.

Since lignin is often associated with hard, tough tissue, and since the tracheal vessels were the principal lignified elements, the relation of these vessels to stringiness must be considered. However, the number of these lignified tracheal tubes seemed to be approximately in proportion to the size of the fibrovascular bundles and therefore seemed to have no relation to stringiness. Lignified tissues are not always of tough, hard texture. There are degrees of lignification and degrees of hardness of lignified tissue, and apparently the lignified elements in the celery plant are not particularly hard or tough.

3. The only celery tissue that seemed to have a very definite relation to stringiness was the collenchyma. A superficial examination of stringy celery would support this belief, for, when a stringy celery stalk is broken so that the strings tear out, it can be readily seen that the strings are in the ribs where the collenchyma strands are found. This is likewise in accordance with statements of plant anatomists to the effect that collenchyma regularly forms the skeletal system of growing organs, and often serves as the permanent mechanical tissue in many fully grown herbaceous structures, such as leaf petioles.

Apparently the relative amount of collenchyma tissue in the ribs is not a factor in causing stringiness, for many of the tender specimens had relatively large strands of collenchyma. The size of the collenchyma cells and the thickness of the cell walls likewise seemed to have no bearing on stringiness of celery. However, there seemed to be a great variation in the degree of hardness of the collenchyma cell walls. Furthermore there was a definite relation between the degree of hardness of the collenchyma tissue and stringiness of the celery petiole. The collenchyma tissue in tough, stringy specimens seemed to be of particularly hard texture, while in tender specimens, both of tender varieties and of inner stalks of tough varieties, the texture of the collenchyma tissue did not seem to be hardened. This was the only morphological factor that seemed correlated with toughness and stringiness in celery.

4. Pithiness is evidently correlated with a breaking down of the parenchyma cells which leaves large open spaces thru the center of the stalk.

5. Flavor seems to be influenced to a greater extent by the variety than by any environmental factors. Of course, proper blanching is essential to good flavor. No morphological conditions could be found that seemed correlated with flavor.

6. The relation between cultural conditions and quality were not clearly developed in this investigation, but the findings regarding differences in structure that are correlated with differences in quality seem conclusive.

LITERATURE CITED

1. AUSTIN, C. F., and WHITE, T. H. Second report on the cause of pithiness in celery. Md. Agr. Exp. Sta. Bul. 93. 1904.
2. BEATTIE, W. R. Celery culture. Orange Judd Co. 1907.
3. HABERLANDT, G. Physiological plant anatomy. Macmillan. 1914.
4. MILLS, H. S. Quality in celery. Market Growers Jour. May 15, 1923.
5. NORTON, J. B. Concerning quality in celery. Vt. Agr. Exp. Sta. Bul. 203. 1917.
6. SANDSTEN, E. P., and WHITE, T. H. An inquiry as to the causes of pithiness in celery. Md. Agr. Exp. Sta. Bul. 83. 1902.
7. STEVENS, W. C. Plant anatomy. P. Blakiston's Son & Co. 1911.
8. THOMPSON, H. C. Celery storage experiments. U. S. Dept. Agr. Bul. 579. 1917.
9. THOMPSON, H. C. Vegetable crops. McGraw-Hill Book Co. 1923.
10. WATTS, R. L. Vegetable gardening. Orange Judd Co. 1914.