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Effect of Tomato Cell Structures on Consistency of Tomato Juice[a]

R. T. Whittenberger and G. C. Nutting
Eastern Regional Research Laboratory,[b] Philadelphia 18, Pennsylvania

THE CONSISTENCY OF TOMATO JUICE depends partly on its chemical composition and partly on its physical structure. Although rather extensive research has been carried out on the chemical constituents, particularly on the pectic substances *(1, 3, 4, 6, 7, 8, 9,* and others*)*, relatively little attention has been given to the structural aspects of consistency *(2, 4, 5, 8, 10)*. The recent work of Hand *et al. (2)* shows that the influence of the insoluble structures on consistency may be much greater than has heretofore been recognized.

Composition and structure are, of course, closely interrelated. Although the insoluble structures may be the building blocks of a juice and may be required for the attainment of an acceptable degree of consistency, their properties and behavior are modified significantly by the presence of pectic substances. In the present study particular emphasis is given to defining the role of the microscopic structures in tomato juice consistency and to showing some of the interrelationships between structure, composition, and consistency.

Structure of tomato flesh cell. To understand the structure of tomato juice, it is helpful to observe the structure of a fresh tomato. A tomato is composed principally of relatively large, near-spherical flesh cells (Figure 1) which are filled with dilute sugar water or cell sap and small quantities of living matter and insoluble granules. The largest cells can barely be seen with the unaided eye. They may be visible as small gelatinous spots as tomato juice drains down the sides of a tumbler. The outer boundary or wall of the cells consists of interwoven cellulose fibrils impregnated with pectic compounds. The walls, although so thin as to be fragile, give mechanical stability to the cells and serve as a supporting framework for tissues. The great intrinsic strength of cellulose as fibers, threads, and fabrics is well known. Pectins are amorphous and, especially when swollen with water or cell sap, have little mechanical strength.

Cells in a tomato are joined by a pectic adhesive which softens as the tomato ripens and permits the cells to separate easily from each other. When the tomato is crushed to make juice, cells separate, sap is released, and cell walls often become broken and distorted. The simple separation of cells from the tissue brings about a very great reduction in viscosity. The cell walls, although separate, remain capable of exerting an important and even predominating influence on juice consistency despite the fact that they amount to a percent or less by weight.

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[b] One of the laboratories of the Eastern Utilization Research Branch, Agricultural Research Service, U. S. Department of Agriculture.

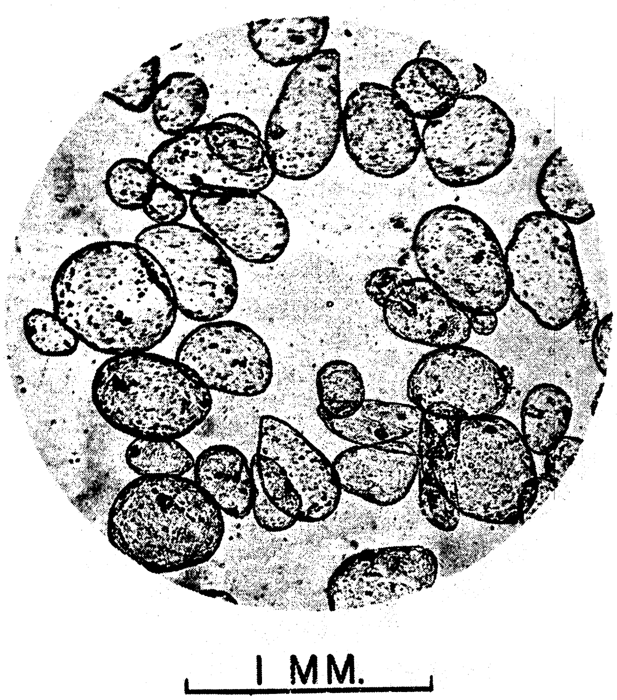

Figure 1. Unstained, living flesh cells from the center of a tomato. Insoluble granules and cell walls are seen.

OBSERVATIONS

Juices from dissected tomatoes. Tomatoes were dissected into the 4 fractions shown in Figure 2: A, the outer rind or shell of the tomato; B, the placenta or center tissues; C, the free juice occurring in the vicinity of the seeds; and D, the gelatinous envelopes surrounding the seeds (Figure 3). With tomatoes averaging 110 g. in weight, fraction A comprised the greatest proportion (48%) of the whole tomatoes (Table 1) and fraction D the smallest (8%).

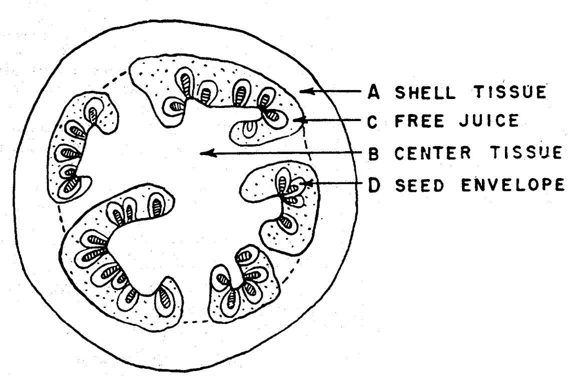

Figure 2. Cross section of a tomato. Tissues separated by dissection are indicated.

Tissues comprising the fractions were converted to juices by being heated to 190° F. and passed through a small Sepra Sieve (a tapered screw-type extractor). Consistency of the juices was measured with a Brookfield viscometer in a manner described by Hand *et al. (2)*, and the viscosity of serums (tomato juice freed from suspended particles) was determined in an Ostwald viscometer. Most photomicrographs of the diluted (1 : 1) juices were taken with the aid of polarized light and crossed Polaroids and a mounting chamber which gave a

Figure 3. Longitudinal section of tomato seed. The outer tissue is the seed envelope, the broad white band comprises the seed coat and seed hairs, and the central dark region is the seed proper. The envelope is folded in part.

uniform film of juice 350 microns thick. Under these conditions only crystalline structures, which in tomatoes are composed principally of cellulose, were brightly visible.

Large differences in the properties and structure of the juices were observed (Table 1). The thickest juice which was 432 apparent centitpoises (cp.), was obtained from the seed envelopes (fraction D). The serum viscosity of this juice also was extremely high (25.6 cp.), indicating the presence of relatively large amounts of undegraded pectic materials. This viscosity was about ten times as high as that of the thickest serum of the commercially available juices studied. During commercial juice manufacture, these pectin-rich envelopes usually, although not always, are stripped from the seeds and are included in the body of the juice. Enzymatic digestion of the

TABLE 1

Properties of juices from different fractions of tomatoes

Fraction of tomato	Juice	Percent of tomato	Consistency of juices, apparent cp.[1]		Viscosity of serum, cp.
			Original	Homogenized	
Shell	A	48	155	405	2.6
Center	B	26	145	335	2.4
Free juice	C	18	11[2]	15[2]	1.3
Envelopes	D	8	432	700[3]	25.6

[1] Recognizing the strong dependence of the viscosity of most tomato juices on the rate of shear, "Brookfield viscosities" of whole juices are throughout the paper designated "consistency" and expressed as "apparent centipoises."

[2] Low viscosities cannot be determined accurately under the measurement conditions used throughout (usually No. 2 rotor, 60 r.p.m.). Indicated viscosity of water was 4 cp. (actually, 1 cp.).

[3] Rotor No. 3 at 60 r.p.m. was used.

pectins in juice D lowered the serum viscosity to 1.2 cp. The principal structures visible in the juice were cell walls (Figure 4). These differed from those of most other cells in the tomato in being more elongated, pliable, elastic, and thinner.

The thinnest juice was obtained from the liquid (fraction C) surrounding the seed envelopes. Its Brookfield viscosity was only 11 apparent cp. and its serum viscosity was 1.3 cp. (see Table 1 footnotes). No structures were visible microscopically under polarized light, although numerous insoluble colored granules could be seen under ordinary illumination. The absence of cell walls from this juice was highly significant.

Juices made from the shell (A) and center (B) tissues were similar and resembled an average commercial tomato juice in properties and appearance. These juices comprised about 75% of the total juice from the dissected tomatoes. Juice A had a consistency of 155 apparent cp. and a serum viscosity of 2.6 cp. Quantities of cell walls were visible under the microscope (Figure 5).

Figure 4. Cell walls in juice from tomato seed envelopes. The walls contained much pectin and the juice was thick.

Consistency of the juices was increased by changing the structure of the insoluble constituents. This was accomplished by treating the juices in a Waring blender, a process analogous to homogenization. The increases were not equal in magnitude but varied with the nature of the insoluble components. Thus juices that contained quantities of cell walls (juices A, B, D) showed large increases, whereas juice C which contained numerous insoluble granules but not cell walls, was scarcely affected. Viscosity of the serums remained almost constant during the blender treatment, thus indicating that no more pectins were extracted or made soluble by homogenization.

Increase in consistency of juices A, B, and D was associated with the conversion of spherical particles to elongated particles and with a reduction in particle size. A comparison of Figures 5 and 6 shows the structural changes in the cell walls of juice A caused by homogenization.

Effect of maturity and preheat treatment. The character and quantity of insoluble structures in tomato juices depended partly on the maturity of tomatoes and on whether the tomatoes were heated before crushing. When hard, green, unheated tomatoes were made into juice (cold break method), relatively few cell walls were incorporated in the juice (Figure 7). The flesh cells stuck together in irregular clumps and most were discarded with the seeds and skins by the extractor. The juice consisted principally of expressed cell sap and small insoluble granules. It was relatively thin (Table 2).

Heating similar whole green tomatoes to a center temperature of 190° F. in a pressure cooker prior to their passage through the extractor (hot break method), resulted in the inclusion of quantities of cell walls in the juice (Figure 8). The heat not only softened the tissues and permitted easy separation

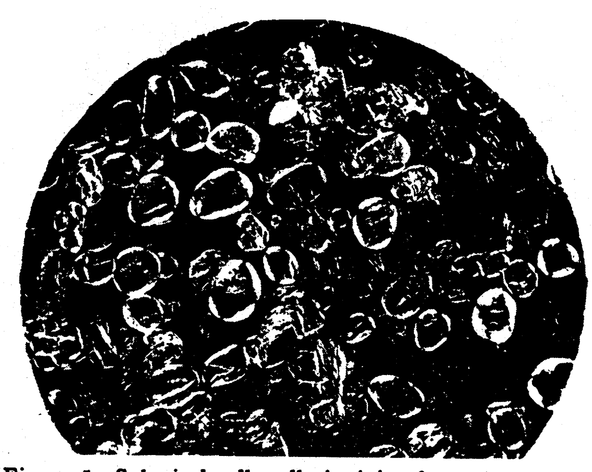

Figure 5. Spherical cell walls in juice from the outer shell of a tomato. Juice was average in consistency.

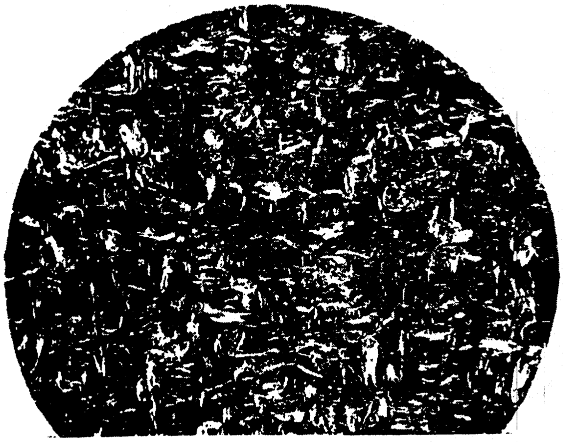

Figure 6. Same juice as in Figure 5 after homogenization in a Waring blender. Increase in linearity of cell walls is evident. Juice was thick.

of cells, but it also preserved the native pectins of the tomatoes. Although the serum viscosity (7.0 cp.) was several fold greater than that of an average commercial hot-break juice, it was insignificantly small in comparison with the viscosity of the whole juice (410 cp.). The juice was exceedingly thick, approximating the consistency of tomato puree.

With ripe tomatoes, differences in preheat treatment made relatively small differences in the amount and shape of cell walls in the resulting juice, although differences in the charac-

TABLE 2
Effect of maturity and preheat treatment of tomatoes on consistency of tomato juice

Maturity of tomatoes	Preheat treatment	Consistency of juice, apparent cp.	Viscosity of serum, cp.
Ripe	None	80	1.3
Ripe	190° F.	160	3.1
Green	None	55	1.9
Green	190° F.	410	7.0

ter of the walls did occur. Both preheated and not preheated whole tomatoes gave juices containing cell walls in quantity. In a ripe tomato the flesh cells were easily separable even without a preheat treatment. The hot break juice, however, was thicker than the cold break juice and contained more pectic materials, as indicated by the viscosity of its serum (3.1 cp.). When pectic materials made up a substantial part of the cell walls, the walls were relatively tacky, strong, and hydrophilic. Both juices were thicker than that from cold break green

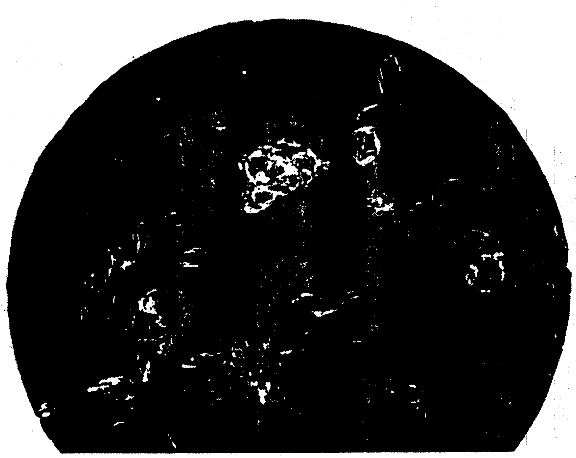

Figure 7. Relatively few cell walls were present in the juice from unheated green tomatoes. Juice was thin.

tomatoes, although neither of the juices was as thick as that from hot break green tomatoes.

Effects of pectinase and cellulase. Removal of pectin from serum and cell walls in a hot break juice by pectinase caused a significant decrease in consistency (Table 3). This decrease was not accompanied by a conspicuous change in the microscopic appearance of cell walls, although the walls did appear to increase slightly in birefringence. Chemical analyses confirmed the elimination of pectins from both the cell walls and the serum. However, consistency of the pectin-free juice was restored and

TABLE 3
Effect of pectinase and cellulase on the consistency of tomato juice

Treatment	Consistency of juice, apparent cp.		Viscosity of serum, cp.
	Original	Homogenized after treatment	
None	131	224	2.3
Pectinase	83	163	1.1
Cellulase (containing pectinase)	58	54	1.1

even made to exceed its original value by changing the structure, i.e., by decreasing the size and increasing the linearity of the residual cellulosic walls in a Waring blender. The blender caused greater splintering of the pectin-free walls than it did of pectin-impregnated walls, thus indicating the change in cell wall character brought about by the removal of pectins. Maximum consistency was obtained by treating the original pectin-containing juice in the blender. Evidently the combined effects of dissolved pectin in raising the serum viscosity and of insoluble pectin in raising the water-holding capacity of the fragmented cell walls more than offset the greater wall fragmentation in the pectin-free juice.

Unfortunately, cellulose-digesting enzymes were not available in pure form. The enzyme preparation used digested pectic sub-

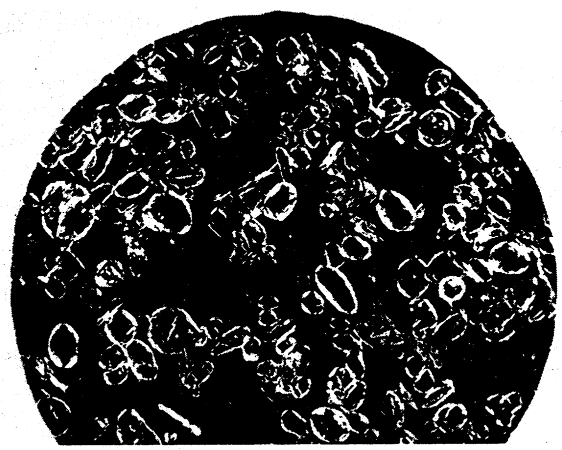

Figure 8. Preheated green tomatoes gave a thick juice containing many cell walls.

stances as well as cellulose. Treatment of the original juice with the preparation lowered consistency appreciably. Essentially all pectic substances were digested, as indicated by the drop in serum viscosity, and the bulk of the cellulose was digested, as indicated by microscopical examination. Only a small number of fragments of the cellulosic walls were visible and these had lost their birefringence. There was no change in the appearance of the insoluble granules.

With the digestion of the major portion of cellulose, consistency of the juice was not restored by homogenization. Although incompletely digested fragments of cellulose were present in sufficient amount to maintain consistency at about 50 cp., the fragments evidently were too small to be affected by the homogenization treatment, just as colloidal molecules of pectin in solution are unaffected. As shown previously, homogenization has almost no effect on consistency of the insoluble granules. The results indicated, therefore, the importance of cellulosic structures both in maintaining consistency and in increasing consistency through homogenization.

DISCUSSION

New evidence is presented showing the importance of physical structure in the consistency of tomato juice. Specifically, plant cell walls are identified as the principal structural elements, or building blocks, of a juice. Without these building blocks, the consistency is trivial. Consistency depends largely on the quantity, shape, degree of subdivison, and character of the cell walls present.

Several factors influence the quantity of cell walls in a juice. Among these are maturity of tomatoes, native differences in cell wall thickness, type of preheat treatment of fresh fruit, and manner of extracting or comminuting tomatoes to form juice. These factors are closely interrelated, and often variations in one factor can be compensated for by adjustments in another. Data in a previous section of this paper and elsewhere *(2, 10)* indicate how some of these adjustments may be made.

Although two juices may contain identical quantities of cell walls, they may differ in consistency because of differences in the configuration, or structural arrangement, of the walls. In general, sheetlike or rodlike walls or wall fragments offer more resistance to flow and give a more stable juice structure than do spherical walls. The irregularity of cell wall form depends largely on the mechanical treatment the walls receive during juice manufacture. Forcing cell walls through passages of small clearance, and other types of shearing, stirring or beating actions increase linearity.

The character of cell walls varies with their pectin content. Walls permeated with pectins are tacky, resilient, and capable of binding appreciable quantities of water, whereas walls devoid of pectins are brittle, friable, and less hydrophilic. Under similar conditions, the pectin-containing walls yield the thicker juices. Many of the same factors that control the cell wall content of a juice also control its pectin content. It is well known that the native pectins of tomatoes may be preserved during juice manufacture by a suitable preheat treatment.

These studies are being continued.

SUMMARY

Microscopic studies showed that the principal structural element in tomato juice is the flesh cell. Of the insoluble structures in the flesh cell, the cell wall was identified as the structure most closely related to consistency.

Tomatoes were dissected into four separate tissue fractions which were converted to juices. Juices from the outer shell and from the center tissues were moderately thick and contained moderate quantities of cell walls. Free juice from the seed cavities was exceedingly thin and was devoid of cell walls. Juice from the gelatinous seed envelopes was thick, and contained cell walls heavily impregnated with pectin. The juices containing cell walls were thickened by increasing the linearity and surface area of the walls through homogenization or equivalent mechanical treatment.

Maturity of tomatoes and preheat treatment affected juice structure, composition, and consistency. Unheated green tomatoes gave a juice low in consistency and cell wall content, and moderately low in pectin content. Whole green tomatoes preheated to 190° F. yielded a juice high in consistency, cell wall content, and pectin content. With ripe tomatoes differences in preheat treatment made smaller differences in juice structure and pectin content. The differences in consistency, however, were great enough to be of practical significance. Although enzymatic digestion of pectin in a juice lowered consistency, consistency was restored by mechanically changing the structure of the pectin-free cell walls. Partial enzymatic digestion of cellulose in the cell walls irreversibly lowered consistency. Maximum consistency was obtained when both cell walls and pectins were present in quantity. It was concluded that consistency depends largely on the quantity, shape, and degree of subdivision of the cell walls present, and on the character of the walls as determined by the occurrence of pectins.

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