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Changes in Pectins and Product Consistency during the Concentration of Tomato Juice to Paste

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Concentrating tomato juice to paste during the tomato season allows for preservation and long-term storage, but subsequent dilution for formulation of value-added products is known to result in a loss of consistency. To understand the reasons for this, samples of unconcentrated juice, processing intermediates, and concentrated paste were collected from an industrial processing plant during normal commercial production. All samples were diluted with water to 5 °Brix and then analyzed for consistency and pectin content. Whole juice consistency, measured with a Bostwick consistometer, decreased through the course of juice concentration, with the largest change occurring early in the process, as the juice was concentrated from 5 to 10 °Brix. This decrease in consistency occurred during the production of paste from both hot- and cold-break juices. The change in Bostwick value was correlated with a decrease in the precipitate weight ratio. The loss of consistency during commercial processing was not the direct result of water removal because a sample of this same 5 °Brix juice could be concentrated 2-fold in a vacuum oven and then diluted back to 5 °Brix with no change in consistency or precipitate ratio. Total pectin content did not change as the juice was concentrated to paste, but the proportion of the total pectin that was water soluble increased. The greatest increases in pectin solubility occurred during the hot break and late in the process where the evaporator temperature was the highest.

KEYWORDS: Tomato paste; consistency; Bostwick; viscosity; pectin

INTRODUCTION

Of the approximately 10−12 million tons of processing tomatoes grown annually in California, the vast majority are thermally processed and concentrated into tomato paste. Concentrated paste is typically stored for 1 year or more, and this stable material is diluted for production of sauces, salsas, and other value-added products. Many variations in the quality of the paste can be obtained depending upon factors, such as the cultivar of tomatoes used, the finisher screen size, and most importantly the break temperature (the temperature to which the tomatoes are initially heated). It has long been known that the break temperature used in tomato processing strongly affects the pectin content and consistency of the final product (*1, 2*). In the hot-break process, the tomatoes are rapidly heated to >90 °C to thermally inactivate enzymes, particularly the pectin degrading enzymes pectin methylesterase (PME) and polygalacturonase (PG). This prevents the enzymatic breakdown of the pectin and results in a high pectin content and high consistency product. In the cold-break process, the tomatoes are heated to only about 65 °C. This lower temperature results in a better color and flavor in the product but at the expense of consistency because PME and PG are highly active at 65 °C, resulting in a product with substantially lower pectin content.

The rheological properties of fluid tomato products, such as sauces and ketchup, are important quality parameters. The flow properties of the whole juice, referred to as the gross viscosity or the consistency, are typically evaluated using a Bostwick consistometer. In this measurement, the distance the juice flows in a trough in 30 s is measured. Other devices, such as efflux pipettes and rheometers, have also been used to measure the apparent viscosity of whole juice. Apparent viscosity and the Bostwick measurements can be directly related to each other (*3*). There is a great deal of evidence that the flow properties of the whole juice are determined primarily by the insoluble material in the juice (*4, 5*). The viscosity of the serum, the soluble fraction of the tomato juice after removal of insoluble material by centrifugation, can be determined using a Cannon−Fenske-type viscometer. This serum viscosity is the result of the solutes present, particularly the polymeric material, which in tomato juice consists mostly of pectin. Both serum viscosity and Bostwick value are routinely determined in quality control evaluations during tomato paste production.

Concentrating tomato juice to paste during the tomato season allows for preservation and long-term storage, but subsequent dilution for formulation of value-added products is known to result in a loss of consistency. This occurs during large-scale

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commercial processing and has been demonstrated numerous times when tomato juice has been concentrated in small benchtop evaporators (*6–10*). Samples collected at various levels of concentration from laboratory-scale evaporators have repeatedly shown that the greatest loss of consistency occurs in the early stages of concentration, as the juice is concentrated from 5 to 10 °Brix, with further concentration to 20 °Brix or higher causing only small additional losses in consistency. This is presumably also the case during commercial processing, but information on this has not been reported. Concentration and subsequent dilution also reduces serum viscosity (*11*).

Several explanations for this loss of consistency have been proposed, including chemical hydrolysis of pectins because of high temperatures in the process (*12*), irreversible polymer dehydration by the high solute concentrations in the paste (*6, 10*), and mechanical shear of the juice particles as they are pumped through the system (*7, 13*). The concentration of juice at commercial processing plants involves heating the juice under reduced pressure to evaporate the water. Typically, this process can take more than 2 h and involves heating the material to 90 °C for portions of the process. Pectins in tomato juice are susceptible to breakdown by acid hydrolysis and β-elimination at elevated temperatures, although recent studies on citrus pectin indicate that, at this temperature and the pH of tomato juice, pectin breakdown rates are quite low (*14*). Because the loss of pectin by enzymatic breakdown, as in the cold-break process, greatly decreases consistency, pectin loss by non-enzymatic thermal breakdown of pectin could also reduce consistency. Several authors have shown that heating tomato serum for extended periods of time causes a loss in viscosity. This was attributed to a loss of pectin, although no direct measurement of pectin was made (*15, 16*). Measurements of the effects of prolonged heating on whole juice consistency have not been reported.

Changes in pectin quantity, solubility, and size properties during the commercial concentration of juice to paste have been reported (*12*).These authors found that during the concentration process there was both a transfer of pectin from the water-insoluble to the water-soluble fraction and there was a large net loss of pectin during the process. In this study, alcohol-insoluble solids (AIS) were prepared from unconcentrated juice, processing intermediates, and concentrated paste. The total pectin content of the AIS prepared from the paste was only half that of the AIS obtained from the original juice. In addition, a decrease in pectin polymer size was observed between fractions solubilized from juice AIS and paste AIS. They concluded that the heat inputs during concentration led to extensive solubilization and thermal hydrolysis of pectin. Because this loss of pectin would be expected to result in reduced consistency, they proposed that reducing heat inputs should improve product quality.

Other data argue against the idea that heat effects are the basis for the loss of consistency. Several authors have shown that, in laboratory-scale evaporators, when juice is concentrated to paste under reduced pressure at temperatures ranging from 25 to 65 °C, the same loss of consistency occurs as is seen during high-temperature processing (*7, 9, 10*). At these lower temperatures, thermal breakdown of pectin would be negligible. Taking this one step further, Beresovsky et al. (*7*) showed that if tomato juice was put in the evaporator but no vacuum or heat was applied, so that no concentration occurred, a loss of consistency was still observed, presumably because of shearing as the juice was mixed in the evaporator. They proposed that changes in consistency during commercial processing could be mostly due to mechanical effects, such as the shear forces on the juice as it is pumped through the system. An irreversible loss in tomato consistency from mechanical shearing has been demonstrated (*13*).

An alternative explanation for the loss in consistency during juice concentration is that the high solute concentration found in the paste compresses the juice particles and induces irreversible cross-linking between biopolymers within the juice particles. In this model, the juice particles cannot fully re-expand upon dilution and the original consistency is not recovered (*6, 10*). Evidence in favor of this hypothesis is an apparent correlation between the Bostwick loss induced by freezing and thawing and that induced by evaporative concentration, both of which increase the local solute concentration surrounding the juice particles (*17*). In this theory, consistency loss is an inevitable consequence of juice concentration and dilution. However, it has also been reported that, if water is removed from juice at ambient temperature with no agitation, no loss of consistency occurs when that juice is rehydrated (*7*)

The purpose of this study was to characterize the changes in consistency and pectin content that occur during the production of tomato paste at a commercial processing plant by analyzing samples of the raw material, processing intermediates, and final product to determine where in the process these changes occur. This information should provide insights into the mechanism by which consistency is lost during tomato paste manufacture.

MATERIALS AND METHODS

Sample Collection. Tomato samples were collected at the Morning Star Packing Co. processing plant in Williams, CA during the 2006 and 2007 seasons. Samples were collected 3 times (once in 2006 and twice in 2007) during production of hot-break paste using high consistency Heinz cultivars of tomatoes, 2 additional times (once in 2006 and once in 2007) during hot-break production using a mixture of other tomato varieties, and once in 2007 during cold-break production. Samples taken from various points in the concentration process were immediately cooled on ice, then soluble solids were determined. The soluble solids of the unconcentrated juice varied from 5.0 to 5.5 °Brix. Sufficient water was added to all samples to bring them to 5.0 °Brix. Mixing was performed by combining the juice concentrate and the water in a polyethylene bag and then kneading the bag by hand until thoroughly blended. Additional water or tomato concentrate was blended as necessary to bring each sample to 5.0 °Brix.

Consistency. Bostwick values were determined at 25 ± 0.5 °C. For serum viscosity and precipitate weight determinations, 30.00 g of the juice samples were centrifuged at 5 °C for 10 min at 14000*g* in a Sorvall centrifuge. The supernatants were collected; then, the weights of the pellets were determined, and the precipitate weight ratio calculated. The viscosities of the supernatants (serum viscosities) were then determined using a Cannon−Fenske-type viscometer at 25 ± 0.5 °C. As is typical in the tomato industry, viscosity values are reported in seconds, normalized to an efflux time of 60 s for water in the same viscometer. Only the samples collected in 2007 were analyzed for serum viscosity.

Pectin Analysis. Pectin analysis followed the procedure as described (*18*). Each sample of juice was analyzed in triplicate. For raw tomatoes, fruit was homogenized in phosphate buffer (pH 2) containing 1 g/L sodium dodecyl sulfate (SDS) to inactivate endogenous enzymes and prevent pectin breakdown.

RESULTS

Process Conditions. The process temperature, approximate residence time, and °Brix of the tomato juice at each stage of hot-break paste production is given in **Table 1**. The initial step in processing is the break tank, where the whole tomatoes are heated and disintegrated. The temperature at this point during

Table 1. Processing Parameters during Hot-Break Paste Production

process stage	sampling point	average soluble solids (°Brix)	approximate temperature (°C)	approximate residence time (min)
whole tomato	1		ambient	
break tank			90−95	5
flash evaporators	2	5.1	60−75	10
third effect evaporator	3	7.7	50	30
second effect evaporator	4	10.9	74	40
first effect evaporator	5	20.3	91	40
high density evaporator			80−90	30
paste	6	28	ambient	

the hot-break process ranged from 90 to 95 °C, with an average of 92 °C. After the break tank, the juice was screened through pulper finishers to remove seeds and large pieces of tomato and then passed through a series of flash evaporators. This was the first point in the process where a sample of the juice could be collected for analysis (step 2). The flash evaporators were then followed by the three main evaporators (steps 3−5). Through the initial stages of the process, the temperature of the juice decreases (**Table 1**), reaching a minimum of 50 °C at the third effect evaporator (step 3) and then increasing to a maximum of 90 °C in the first effect evaporator (step 5). The material then passes through a high-density concentrator at slightly lower temperatures for the final concentration to paste (step 6). In the hot-break process, the soluble solids content increased from an average of 5.1 °Brix at the start of concentration to a final level of 28 °Brix. Process conditions for cold-break paste production were similar, except that the temperature in the break tank was 64 °C and higher soluble solids levels were obtained at sampling points 4−6, reaching 37 °Brix in the final product.

Bostwick Consistency. Samples of tomato material were collected at each of the stages of the process and then diluted with water back to the starting material level of 5 °Brix of the starting material before comparing consistencies. As has been observed previously, juice prepared by diluting concentrated material had a lower consistency (higher Bostwick value) than the original unconcentrated juice (**Figure 1**). This effect was observed on all days that the process was sampled and was true for both cold- and hot-break juices. As would be expected, the cold-break juices had substantially higher Bostwick values than the hot-break juices at all stages in the process. For both types of juices, the greatest change in Bostwick consistency occurred early in the process, between steps 2 and 4, as the juice was concentrated from 5 to 10 °Brix. Bostwick values were

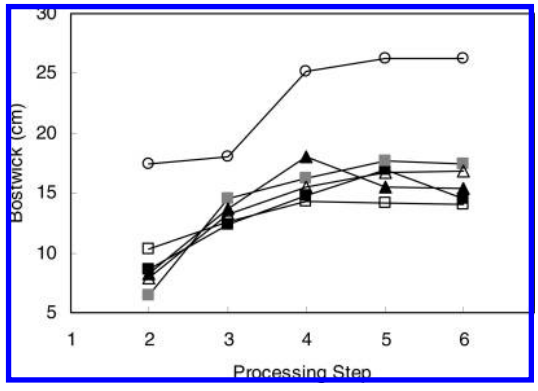

Figure 1. Change in Bostwick during paste processing. Samples were collected during production of cold-break paste (○), hot-break paste from Heinz varieties (■), or hot-break paste from unspecified tomato varieties (▲).

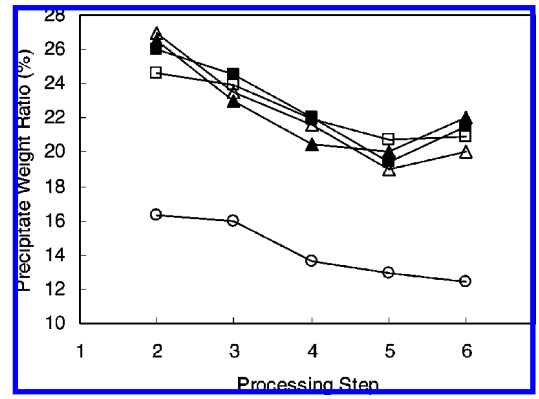

Figure 2. Precipitate weight ratios for samples shown in **Figure 1**.

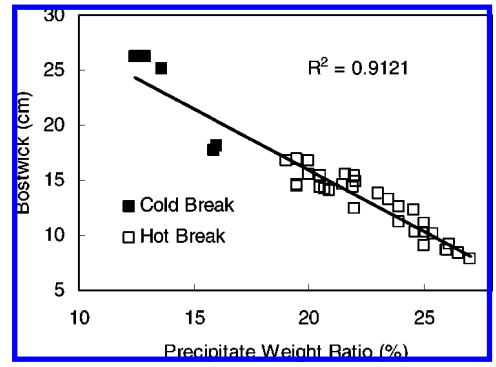

Figure 3. Correlation between Bostwick and precipitate weight ratio for hot- and cold-break samples in **Figures 1** and **2**.

determined immediately after reconstitution on the day of production. No further changes in Bostwick were observed if the reconstituted juices were allowed to stand 24 h at room temperature or if they were heated (30 min at 90 °C). This is in contrast to an earlier report, where heating was reported to partially reverse the consistency loss caused by juice concentration (*6*).

The precipitate weight ratio, defined as the weight ratio of the pellet formed by centrifugation to the weight of juice centrifuged, has been shown to be well-correlated with Bostwick values in tomato juice (*19*). In agreement with this, samples collected at the later stages in the process, which had the highest Bostwick values, had the lowest precipitate weight ratios (**Figure 2**). The lowest precipitate ratios were obtained from samples collected during cold-break processing. A simple linear correlation between this ratio and the Bostwick was found (**Figure 3**).

To test whether water removal by itself could cause a loss of consistency, a sample of hot-break juice collected at step 2 was put in a beaker and allowed to evaporate at 30 °C in a vacuum oven with no stirring. When just over half the water had been removed (the same level of concentration that occurred in the commercial process at step 4), water was added back and the Bostwick and precipitate ratios were determined. In comparison to the original unconcentrated hot-break juice, this juice showed no change in either Bostwick or precipitate ratio (**Table 2**). By contrast, commercial processing of this same juice to this same level of concentration caused substantial changes in both parameters.

Serum Viscosity. Serum viscosities declined through paste processing. The overall decrease in viscosity between unconcentrated hot-break juice and paste reconstituted to 5 °Brix ranged from 31 to 37% for the 3 days of hot-break processing on which serum viscosities were determined. Serums prepared

Table 2. Effects of the Juice Concentration during Commercial Processing or in a Vacuum Oven on Bostwick and Precipitate Weight Ratios[a]

	concentration factor	Bostwick after dilution (cm)	precipitate weight ratio (%)
hot break juice (step 2)	1.0	8.6 ± 0.0	25.0 ± 0.3
processing step 4	2.1	14.8 ± 0.1	20.4 ± 0.5
vacuum oven concentrated	2.1	8.5 ± 0.2	25.1 ± 0.5

[a] In both cases, the same hot break juice was concentrated to the same extent and then diluted and assayed. Bostwick values and precipitate weight ratios were determined in triplicate.

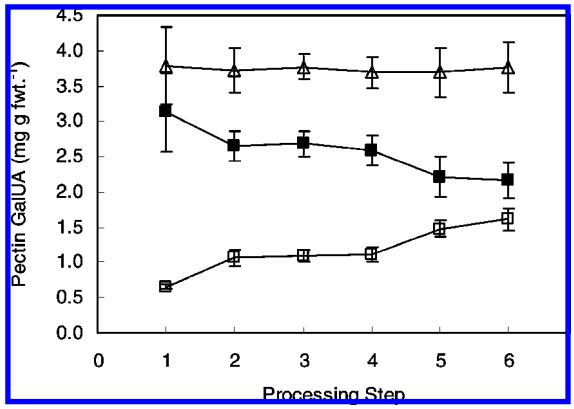

Figure 4. Soluble (□), insoluble (■), and total (△) pectin through hot-break paste processing. Data are the averages from samples collected on 3 separate days of production of Heinz varieties of tomatoes. Error bars indicate one standard deviation.

from juices collected during cold-break processing had much lower serum viscosities (<90 s), which changed little during the process (data not shown).

Pectin Analysis. The soluble and insoluble pectin content of the 5 °Brix dilutions of the hot-break processing intermediates as well as those from the raw unprocessed tomatoes entering the plant were determined. Juices were first separated into a soluble and insoluble fraction by centrifugation, and then the pectin content of each was determined. Total pectin was calculated by summing these two measurements. The total pectin galacturonic content of the raw unprocessed tomatoes was 3.8 mg g fwt.$^{-1}$. Only a small portion of this pectin was soluble. During the course of processing, the amount of soluble pectin increased, mirrored by a decrease in the amount of insoluble pectin (**Figure 4**). Total pectin, however, showed essentially no change through the process, equaling between 3.7 and 3.8 mg g fwt.$^{-1}$ at all stages of the process. The amount of soluble pectin, when expressed as a percent of the total pectin, increased (**Figure 5**) from 18% in the raw tomato (step 1) to 43% in the final product (step 6). The only significant increases in pectin solubility occurred during the hot-break (between steps 1 and 2) and in the first effect evaporator (step 5). These are the two hottest points in the process (**Table 1**).

Pectin levels in the cold break production samples were substantially lower than those found in the unprocessed tomatoes or samples collected during hot-break processing. This is expected, given the presence of active pectin hydrolyzing enzymes during the cold break. Total pectin in unconcentrated cold-break juice (step 2) was 1.6 mg g fwt.$^{-1}$ (**Figure 6**). This decreased to 1.3 mg g fwt.$^{-1}$ in the final product. This small pectin loss during concentration could be the result of the continuing action of polygalacturonase because the process does not reach a temperature sufficient to inactivate the heat-resistant form of polygalacturonase (>90 °C) until the first effect evaporator (step 5).

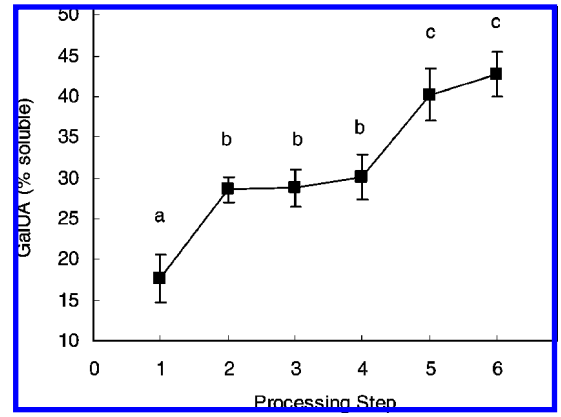

Figure 5. Results from **Figure 4** expressed as the percent of total pectin that was soluble. Error bars indicate one standard deviation. Data points marked with the same letter are not significantly different ($p < 0.05$).

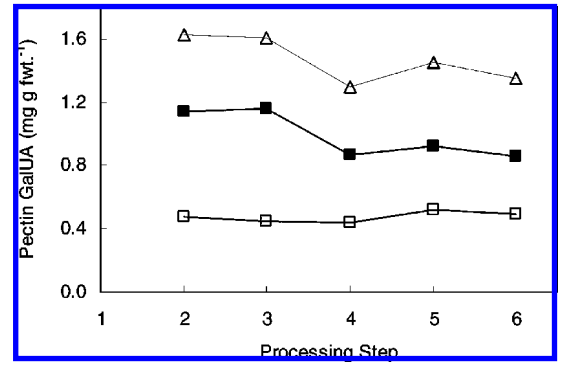

Figure 6. Soluble (□), insoluble (■), and total (△) pectin through cold-break paste processing. Data are from samples collected on a single day of processing.

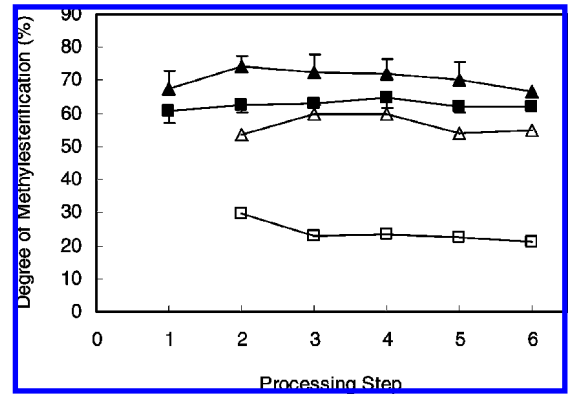

Figure 7. Degrees of methylesterification of the soluble (▲) and insoluble (■) pectins from hot-break processing. Degrees of methylesteification of the soluble (△) insoluble (□) pectins from cold-break processing. Hot-break determinations are the averages from samples collected on 3 days of processing; cold-break samples are from a single day. Unprocessed whole tomatoes (step 1) were not sampled on the day of cold-break production. Error bars indicate one standard deviation.

The degree of pectin methylesterification (DM) showed no apparent change during concentration of either hot- or cold-break juice. The DM of the various hot-break processing intermediates ranged from 62 to 65% for the soluble pectin and from 68 to 74% for the insoluble pectin (**Figure 7**). These are very similar to the DM obtained for the unprocessed whole tomatoes (step 1), indicating that the hot-break process was effective in inactivating PME, preventing any enzymatic hydrolysis of the pectin methylesters. No significant change ($p <$

0.05) in DM of either the soluble or insoluble pectin occurred as the hot-break juice was concentrated to paste. The DM of the cold-break intermediates were lower, as would be expected from the action of PME during the cold break. Lower DM for pectins from cold- versus hot-break pastes have previously been reported (*18, 20*). The lack of any change in the DM as the cold-break juice was concentrated to paste indicates that either all susceptible methylesters were hydrolyzed during the cold-break or the process temperature at step 2 was high enough (>70 °C) to inactivate PME, preventing any further enzymatic de-esterification later in the process.

DISCUSSION

It is well-known that concentrating tomato juice to paste and then later diluting the paste back to juice results in a loss of consistency. Our results confirm that this loss of consistency occurs during commercial production of both hot- and cold-break pastes. It is generally agreed that the consistency of tomato juice, as measured by the Bostwick value, is mostly determined by the amount and properties of the water-insoluble solids (*4, 5, 19*). Consistent with this, the precipitate weight ratio, which is a measure of the volume of the insoluble fraction, was well-correlated with the Bostwick value for both hot- and cold-break material (**Figure 3**). This has been observed by others and has been interpreted as showing that consistency depends upon the volume within the juice that is occupied by the water-insoluble solids (*19*). The nature of the change in the water-insoluble solids during processing that causes this volume to decrease and the Bostwick value to increase is not clear.

Our results indicate that, except for some solubilization, there are no substantial non-enzymatic changes to the pectins during juice concentration. For both cold- and hot-break juices, the degree of methylesterification showed no change through processing. During hot-break paste production, the total amount of pectin did not change and was the same as that found in the raw tomato, indicating that there was no loss of pectin by thermal hydrolysis (**Figure 4**). These results are consistent with our earlier measurements on the kinetics of citrus pectin hydrolysis (*14*). At the pH of tomato juice (pH 4.5), the rate of hydrolysis of purified pectin in buffer was very low at the temperatures relevant to tomato paste processing (≤95 °C). For example, with a 10 mg/mL solution of citrus pectin (degree of esterification ~5%), heating for 2 h at 95 °C caused only a 2% increase in the number of reducing ends. Pectins with higher degrees of methylesterification (as occur in tomato juice) showed considerably lower hydrolysis rates. Partially purified tomato pectins gave results that were similar to those obtained with purified citrus pectin (data not shown). From this, it can be concluded that, at pH 4.5 and at the temperatures encountered during paste production (≤95 °C), very little hydrolysis of pectins in tomato juice (degree of methylesterification approx 60%) is likely to occur, which agrees with the results presented here (**Figure 4**).

Our conclusion that little if any pectin hydrolysis occurs during paste production is in sharp contrast to an earlier study (*12*), where it was reported that half the total pectin was lost. It is unlikely that differences in processing conditions are responsible for these divergent results, because the two studies were performed at the same processing plant, operating under similar conditions, and using similar tomato varieties. We cannot offer a good explanation for why these earlier results are so different from ours other than there were differences in methodologies used to prepare the samples for pectin analysis. Their conclusion that half the pectin was lost during processing was based on the measurement of the total uronide content of cell-wall material isolated by ethanol precipitation. It is possible that this precipitation was not equally effective for samples from different steps in the process, which would have contained substantially different amounts of cell-wall material. Our analysis involved diluting all samples with water to the same soluble solids content as the original juice then directly determining the soluble and insoluble pectin content of these dilutions without ethanol precipitation.

The large net loss of pectin reported earlier (*12*) also appears inconsistent with other data presented in that same paper. For a large net loss of pectin to have occurred, hydrolysis during processing must have been so extensive that more than half the total mass of pectin was reduced to uronic acid monomers and oligomers too small to be precipitated by 80% ethanol. However, their analysis of pectin size by gel-filtration chromatography showed that the average molecular weight of those pectin polymers that were ethanol-precipitated decreased only slightly. Apparently, during processing, the hydrolysis of these polymers was very limited. It is difficult to envision a mechanism, especially for a non-enzymatic process, in which half of the pectin polymers are extensively depolymerized yet the remaining half are virtually unaffected. On the basis of both the data presented here, which shows that the total amount of pectin in tomato juice is unchanged by processing and our previously reported data for hydrolysis of purified citrus pectins in solution (*14*), we believe that the pectin polymers actually undergo very limited hydrolysis during tomato paste production.

Even limited pectin hydrolysis could result in a substantial reduction in average pectin molecular weight, which could affect consistency. A reduction in water-soluble pectin molecular weight would, for instance, account for the one-third reduction in serum viscosity that we observed here. However, in their earlier analysis of pectins from samples collected at this same processing plant, Hurtado et al. (*12*) found no reduction in molecular weight in the water-soluble pectins. Others have also reported that serum pectin molecular weight does not change when juice is concentrated to paste (*21*). We are currently characterizing, using size-exclusion chromatography coupled with multiple-angle laser light scattering (SEC−MALLS), the changes in soluble pectin molecular weight and conformation that occur during tomato paste processing (Diaz et al., in preparation).

The pectin content of the juice is clearly an important factor in the consistency, as shown by the fact that if pectins are lost, such as occurs through enzyme activity during a cold break, consistency is reduced (*2, 22*). While there was little or no change in the total pectin content during juice concentration, for both hot- and cold-break juices, the amount of insoluble pectin decreased through both processes (**Figures 4** and **6**). Because juice consistency is determined mostly by the insoluble material, it is possible that this loss of insoluble pectin is a factor in the increase in the Bostwick value. However, during the juice evaporation portion of the hot-break process (i.e., after step 2), the greatest transfer of pectin from the insoluble to the soluble fraction occurred at steps 5 and 6 (**Figure 5**), while the greatest change in Bostwick occurred earlier, before step 4 (**Figure 1**). This argues that the two are not directly connected. The loss of Bostwick early in the process, where the temperature is the lowest, also suggests that the loss of Bostwick is not the result of heat inputs. This agrees with earlier reports, where the consistency

loss was greatest at the initial stages of concentration and occurred at temperatures too low to cause pectin hydrolysis (*7, 9, 10*).

It has also been proposed that the changes in consistency observed during juice concentration are an unavoidable consequence of the concentration process, the result of the high osmotic and ionic strength of the concentrated juice causing irreversible deleterious changes in the juice particles (*6, 17*). One piece of evidence offered as support for this proposal is an observed decrease in average particle size as juice is concentrated to paste. This is interpreted as showing that high solute concentrations cause irreversible deformation and compression of the juice particles, reducing the volume fraction that they occupy and thus altering the rheological properties of the juice (*9, 10, 17*). Our data on the decrease in precipitate ratio (**Figure 2**) could be taken as further evidence that the volume of the juice particles is irreversibly reduced by juice concentration. However, in this model, consistency loss is an inherent consequence of juice concentration. As shown here (**Table 2**) and in agreement with previous results (*7*), under laboratory conditions in the absence of any agitation, juice can be concentrated and then rediluted without any change in consistency. This strongly indicates that, while high solute concentrations could play a role in the mechanism for consistency loss during processing, water removal by itself is not sufficient. A reduction in particle size and precipitate ratio may still be directly related to the observed loss in consistency but could be the result of mechanical damage rather than solute concentration effects. A further analysis of shear effects on juice particle size, precipitate ratio, and consistency, performed in the absence of applied heat or vacuum, should clarify this. The fact that, under certain laboratory conditions, juice can be concentrated and then diluted without any loss in consistency suggests that reducing the extent of consistency loss during commercial paste production may be possible.

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