# EFFECTS OF MATURITY AND PROCESSING VARIABLES ON HEAT PENETRATION TIMES, FIRMNESS, AND DRAINED WEIGHT OF DICED TOMATOES (HALLEY BOS 3155 *CV*)

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## ABSTRACT

*The effects of harvest maturity and processing variables on heat penetration times, firmness, and drained weight of Halley Bos 3155* cv *diced tomatoes were evaluated. Core and flesh tissue of green and red tomatoes were cut into cubes (1.27 or 1.91 cm per side), calcium treated, and processed at either 90.5 or 96.1C. Water and tomato juice were used as processing and cooling mediums. Heat penetration time was determined mainly by dice size and type, while firmness was determined by dice type and calcification. Heat penetration times were faster into 1.27 cm dices. Green cores heated fastest followed by red cores, then red dices. Red cores were significantly firmer than red dice in both raw and processed samples, possibly due to greater amounts of lignin and less locular tissue. Drained weight, which averaged 75 to 88%, did not correlate to any of the maturity or processing variables.*

## INTRODUCTION

California produces over 85% of the U.S. supply of processing tomatoes, or approximately 11.0 million tons in 1999 (USDA 1999). About 20 to 25% of these tomatoes are processed into value-added products, such as diced tomatoes. This study was conducted at the request of a tomato processor to determine the effects of tomato maturity and processing variables on heat penetration times, firmness, and drained weight of diced tomatoes.

Most processing tomatoes in the U.S. are harvested mechanically after 80 to 90% of the fruit in the field has turned red (Downing 1996; Barrett *et al.*

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1998), however green and pink fruit still exist in the field. The Processing Tomato Advisory Board (PTAB), a third party inspection service paid for by growers and processors, allows a maximum of 4% green fruit in any load of tomatoes. Processors are concerned whether these green tomatoes would require longer heating times than red tomatoes to achieve the same degree of lethality. Ways to measure degree of lethality include heat penetration times (indirect) and firmness measurements (direct).

Several instrumental texture studies have been conducted to evaluate tomato firmness as affected by maturity. Barrett and Garcia (1997) evaluated textural properties of seven different varieties of raw tomato fruit at the pink, red, and overripe red stages, and found that firmness declined with increasing maturity for most varieties, including Halley Bos 3155 *cv*. Kader *et al.* (1978) also found that firmness decreased significantly in mature green, breaker, turning, pink, light red, and red 'Cal Ace' tomatoes as ripening progressed. Tomato tissue softening is partly attributed to the action of pectic enzymes, specifically pectinmethylesterase (PME, pectin pectylhydrolase, EC 3.1.1.11) and polygalacturonase (PG, poly-α-1, 4-galacturonide glycanohydrolase, EC 3.2.1.15; 3.2.1.67). PME catalyzes methyl ester hydrolysis on polygalacturonic acid residues, which allows for depolymerization via PG hydrolysis to occur (Pressey and Avants 1992). It has been shown that PME isozymes are present in unripe green tomatoes (Pressey and Avants 1972), while PG does not appear until the onset of ripening (Pressey and Avants 1982). Studies report that thermostable PME is inactivated after 5 min at 67C (Pressey and Avants 1992), and PG after 5 min at 90C in red ripe tomatoes (Pressey and Avants 1973).

Varying pectic enzyme activities have also been found to originate in different parts of the tomato. For example, PG synthesis reportedly originates in the columellar region of red tomatoes, followed by the endo- and exo-pericarp regions (Tieman and Handa 1989). Tissue from some parts of the tomato may also contain different physiological properties, such as lignin near the stem scar region (Taiz and Zeiger 1991), and thus may show different firmness and heat penetration properties.

The diced tomato industry commonly measures drained weight as a gross indicator of yield and firmness in the diced tomato industry (Barrett *et al.* 1998). It is a measurement of the yield and the amount of processed product sold to consumers, and is used to ensure consistency and quality. Commercial processors typically measure drained weights after diced tomatoes are processed, packaged, and cooled to room temperature. According to the U.S. Standards for Grades of Whole Canned Tomatoes, drained weights for U.S. Grade A (Fancy) tomatoes must not be less than 66% of the weight capacity of the container, U.S. Grade B (Standard) not less than 58%, and U.S. Grade C (Substandard) not less than 50% (USDA 1999).

Other variables in the diced tomato process, which may affect heating time and subsequently firmness, include dice size and processing medium. Dice size depends on the desired final product and is limited by the need to ensure adequate heat penetration to inactivate pectic enzymes and spoilage microorganisms (Downing 1996). Typical dice sizes used in the industry include: 1/2 × 1/2 × 1/2 in. (1.3 × 1.3 × 1.3 cm) and 1 × 3/4 × 3/4 in. (2.5 × 1.9 × 1.9 cm) (Downing 1996). The diced tomato industry commonly processes with water, tomato juice, or steam, and processors may utilize either hot-filling into 55 gallon drums, filling into cans and retorting, or aseptically bulk-filling into 55 gallon drums or 300 gallon bag-in-box containers and cooling under room temperature or cold water sprays (Downing 1996). In addition, diced tomato processors usually add calcium to their diced products to impart a firming effect by passing them through a $CaCl_2$ bath or spray prior to processing (Downing 1996). Some processors are concerned that juice, which contains high amounts of sugar and pectic material, may affect heating properties of the medium and subsequently diced tomato firmness.

The objectives of this experiment were to evaluate the effects of dice size, dice tissue type, processing medium, and temperature on: (1) heat penetration times, (2) firmness and (3) drained weight of diced tomatoes.

## MATERIALS AND METHODS

### Heat Penetration Study

Red (USDA stage 6) and green (USDA stage 1) tomatoes of the Halley Bos 3155 *cv* were mechanically harvested from commercial fields in Yolo County, CA and sorted to remove defects. Tomatoes were hand-peeled after submerging in boiling water for 1 min, followed by ice water for 1 min to crack the skin. The experimental design for the heat penetration study is outlined in Table 1.

Peeled tomatoes were hand-diced using serrated knives spaced either 1.91 cm or 1.27 cm apart to produce dice of two sizes: 1.91 × 1.91 × 1.91 cm (3/4 × 3/4 × 3/4 in.), or 1.27 × 1.27 × 1.27 cm (1/2 × 1/2 × 1/2 in.). The more easily hand-cut 3/4 × 3/4 × 3/4 in. dice were used instead of the industry-standard of 1 × 3/4 × 3/4 in. "Red core," "red dice," and "green core" were cut from the central columellar tissue of either red or green fruit. Core material was cut from the dense columellar tissue located immediately below the stem scar, whereas dice material was cut from the remainder of the central columellar tissue below the core. Some red diced material in the larger size (3/4 × 3/4 × 3/4 in. dices) contained both columellar and locular tissue. Green dice of this size were not used because most of the green tomatoes did not yet contain locular material and therefore were not fully square.

TABLE 1.
DICED TOMATO STUDY EXPERIMENTAL DESIGN [1]

| Processing Medium | Dice Type | Dice Size (cm) | $CaCl_2$ Treatment [2] | Processing Temperature (°C) | Cooling Medium (12.7°C) [3] |
|---|---|---|---|---|---|
| Water | Green Core | 1.91 | + | 90.5 | |
| | | 1.91 | + | 96.1 | |
| | | 1.91 | - | 90.5 | |
| | | 1.91 | - | 96.1 | |
| | Red Dice | 1.91 | + | 90.5 | Water |
| | | 1.91 | + | 96.1 | Water |
| | | 1.91 | - | 90.5 | Water |
| | | 1.91 | - | 96.1 | Water |
| | Red Core | 1.91 | + | 90.5 | Water |
| | | 1.91 | + | 96.1 | Water |
| | | 1.91 | - | 90.5 | Water |
| | | 1.91 | - | 96.1 | Water |
| Juice | Green Core | 1.91 | + | 90.5 | |
| | | 1.91 | + | 96.1 | |
| | | 1.91 | - | 90.5 | |
| | | 1.91 | - | 96.1 | |
| | | 1.27 | + | 90.5 | |
| | | 1.27 | + | 96.1 | |
| | Red Dice | 1.91 | + | 90.5 | Water & Juice |
| | | 1.91 | + | 96.1 | Water & Juice |
| | | 1.91 | - | 90.5 | |
| | | 1.91 | - | 96.1 | |
| | | 1.27 | + | 90.5 | Juice |
| | | 1.27 | + | 96.1 | Juice |
| | Red Core | 1.91 | + | 90.5 | |
| | | 1.91 | + | 96.1 | |
| | | 1.91 | - | 90.5 | |
| | | 1.91 | - | 96.1 | |
| | | 1.27 | + | 90.5 | |
| | | 1.27 | + | 96.1 | |

[1] All treatments minus cooling medium variables were conducted for the heat penetration study.
[2] 0.5% Calcium Chloride Solution for 1 min at 35C.
[3] Applies only for firmness and drained weight studies.

Room temperature green core, red core, and red diced tomatoes were processed in water or clarified tomato juice at either 90.5 or 96.1C (Table 1). These temperatures were chosen based on industry specifications. Internal dice temperature was measured by thermocouples using the equipment and method described in a previous study (Ma and Barrett 2001). The only modifications in this study were: water bath temperature (90.5 or 96.1C), calcium chloride concentration (0.5%), and processing medium (water and clarified tomato juice).

Clarified tomato juice was obtained by centrifuging tomato juice (5.2 to 5.5°Brix) supplied by a commercial processor at 10,000 × g for 7 min and then separating the supernatant. The processing medium was heated to the target temperature in a covered circulating water bath (Model PC+20B, Julabo USA, Kutztown, PA) prior to initiation of the study. The bath contained 4.6 L of liquid which was pumped at a rate of 2 L per min.

Each sample consisted of five dice pieces, which were immersed in a 0.5% calcium chloride solution ($CaCl_2$ dihydrate, Fisher Scientific, Fairlawn, NJ) at 35C for 1 min, then immediately transferred and cooked in the processing medium. The uncalcified samples were immediately heat processed. The dices were cooked to a final geometric center temperature of either 90.5 or 96.1C. Heat penetration time was the average time it took the 5 diced pieces to reach the internal target temperature. All process combinations were carried out in duplicate.

**Firmness and Drained Weight Study**

The minimum amount of time required for penetration to the center of each dice type, as determined in the heat penetration study, was used as the process time for the firmness and drained weight study. The experimental design for these studies is shown in Table 1. Eight hundred grams of diced tomatoes were used per process combination, and each process combination was conducted in duplicate. The 800 g sample was dipped in a calcium chloride solution (0.5%, 35C for 1 min) if so designated, processed in water or juice, and then transferred to a cooling bath containing 4.6 L of water or juice at 12.7C for 1 min. Processed samples were drained after cooling using a U.S. No. 8 sieve for 1 min and weighed for drained weight determinations (21 CFR 155.190 1994). Drained weight measurements were conducted in duplicate.

Each 800 g sample was divided into three 200 g samples for triplicate firmness measurements. Firmness of red dices and red core tomatoes was evaluated with a Kramer shear compression test using a TA.XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY). Shear compression tests were executed using a 5-blade probe and test speed of 1.0 mm/s. Force required to compress the sample to 90% strain was recorded. Firmness values were taken as the area under the curve from start to maximum peak. Raw red diced and red core samples were used as controls. Drained weight was calculated for each sample as:

$$\text{Drained wt (\%)} = (\text{Sample wt after cooling / Wt of raw sample}) \times 100$$

### Density Measurements

The density of preweighed 1.91 cm red core, red dice, and green core pieces (20 per dice type) was measured using a water displacement method, and recorded as grams per mL.

### Statistical Analysis

Data was analyzed using ANOVA and Least Significant Difference (LSD) tests at the 95% confidence level.

## RESULTS AND DISCUSSION

### Heat Penetration Study

The time required for each dice (n = 5, N = 2 reps) to reach its target temperature was averaged and taken as the heat penetration time. Statistical analysis was conducted on each variable. In terms of dice type, 1.91 cm green cores heated significantly faster ($P<0.05$) than red dice at 90.5C (Fig. 1). Red cores were not significantly different from either the green core or red dice. Green cores had an average heat penetration time of 6 min 2 s, red cores required 6 min and 16 s, and red dice required 6 min 29 s. One explanation for these findings may be that green tomato cell walls are generally thicker and less fragile than red cell walls, which undergo a greater strain due to cell expansion as well as solubilization during tomato maturation (Mohr and Stein 1969; Seymour *et al.* 1987; Jackman and Stanley 1995). Therefore, cell walls in green diced tomatoes may be strong enough to withstand high temperatures and are less easily ruptured, thereby providing a strong network for heat conduction.

Heat penetration times for red dice and red cores were not significantly different from each other, possibly because the compositional properties of these tissues were similar. Both were cut from the columellar tissue of the same tomato, but cores were located immediately below the stem scar. Although not significantly different, red cores heated slightly faster than red dice, possibly because cores contain greater amounts of lignin and are made up of thicker-walled cells than dice (Taiz and Zeiger 1991) which may allow for better heat conduction. The heat penetration times calculated for all red dice and red cores were adequate for complete inactivation of PME and PG according to previous studies (Pressey and Avants 1992, 1973). A previous study by the authors (Ma and Barrett 2001) included heat penetration curves and calculated lethalities in 1.27 cm (1/2 in.) and 2.54 cm (1 in.) red diced tomatoes. From this study it was predicted that red tomatoes processed at 92C had a heat penetration time of 166 s (2 min 46 s) for 1.27 cm dice size and 653 s (10 min 32 s) for 2.54 in.

dice size. In the present study, 1.91 cm dice were used, which had an intermediate heat penetration time.

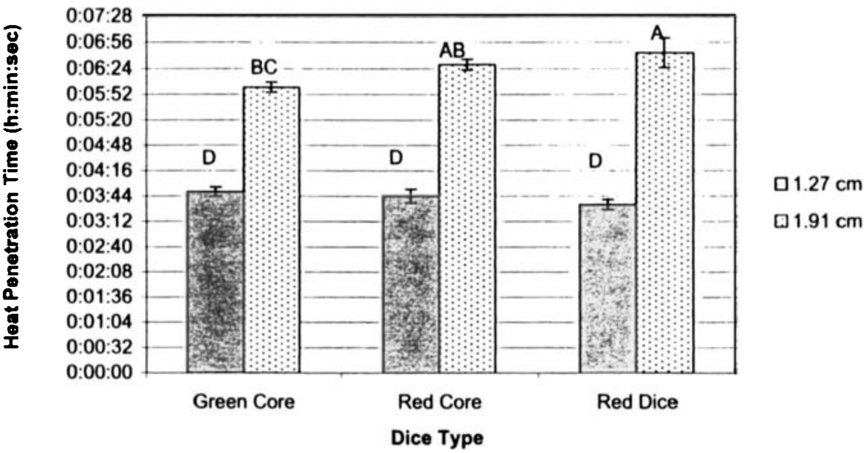


FIG. 1. HEAT PENETRATION TIMES THROUGH CALCIFIED DICED TOMATOES OF TWO SIZES PROCESSED IN JUICE AT 90.5C
(LSD 95% confidence level).

The density results for different diced tomato types showed the same pattern as that of the heat penetration data, where green cores were significantly less dense than red dice, and red cores were not significantly different from either dice type (Table 2). The lower density of green cores may reflect less solubilized protopectic material (Mohr and Stein 1969), and thus a stronger network for heat conduction.

The heating patterns seen in 1.91 cm dice size were not exhibited in the 1.27 cm dice size (Fig. 1). This may have been due to the larger thermocouple thickness to dice size ratio, resulting in a greater conduction error in the 1.27 cm pieces. A recommendation for future studies would be to use smaller gauge thermocouple wire for heat conductivity measurements. The average overall heat penetration time of 1.27 cm dice regardless of temperature and dice type was 3 min and 33 s. These times were only slightly longer than those calculated for 1.27 cm dice in the previous study by Ma and Barrett (2001), which found a predicted heating time of 2 min 46 s for red diced tomatoes. All 1.27 cm diced tomatoes heated significantly faster ($P<0.05$) than 1.91 cm samples as expected due to the shorter distance for heat to travel from dice surface to geometric center.

TABLE 2.
DENSITY OF THREE TYPES OF TOMATO TISSUE FROM HALLEY BOS 3155 CULTIVAR

| Dice Type | Density[1] (g/ml) | Standard Error (n=20) |
|---|---|---|
| Green Core | 0.882[a] | 0.029 |
| Red Core | 0.985[ab] | 0.057 |
| Red Dice | 1.016[b] | 0.035 |

[1] Significance at the 95% Confidence Level, LSD test

There were no significant differences in heating times between samples cooked in water or juice at either 90.5 or 96.1C (data not shown). Tomato juice is often used as a heating medium for diced tomatoes and processors are interested in differences in heating rates between it and water. The industry is considering the use of clarified tomato juice because this may reduce the loss of soluble solids from the product. Castaldo *et al.* (1996) found that the use of clarified tomato serum did reduce losses of both sugars and acids from diced tomatoes during heating. Tomato juice was also clarified in the present study to facilitate pumping through the circulating water bath. Samples should theoretically heat slower in juice than in water, as pulpy juice has a lower thermal conductivity than water. However, the juice used in this experiment was centrifuged to clarify it, and was not greatly different in consistency from water. Any differences observed in heat penetration time between the two heating mediums do not appear to be a real effect. In addition, calcification of the samples did not result in any consistent differences in heating pattern between the two processes.

These findings address some concerns of processors. Green core diced tomatoes do not require a longer cooking time than red diced tomatoes, and the smaller dice (1.27 cm) heated significantly faster than the larger size (1.91 cm). Furthermore, calcification at 0.5% concentration for 1 min and the use of processing mediums used did not affect heat penetration times.

### Firmness and Drained Weight Study

Red cores were firmer than red dice regardless of calcification or processing treatment (Fig. 2). This may be because the tissue below the stem scar contains rigid lignin (Taiz and Zeiger 1991), while flesh sections do not and have been shown to precede the stem end in softening (Jen and Paynter 1971). Red cores also visibly contained less locular gel material, which has been shown to be more prone to deformation (Hamson 1952), and greatly affects tomato firmness (Jackman and Stanley 1995). Visual observations confirmed that the locular material in the red dice was less firm than the parenchymatous tissues. There have been no studies conducted investigating the effects of locular material on overall tomato texture because of the difficulty in measuring locular firmness (Barrett *et al.* 1998). Although time restrictions prevented investigation in the present study, future research may focus on firmness differences between green and red diced tomatoes.

Calcification increased both raw red dice and red core firmness (Fig. 2). Raw red core firmness increased significantly from 4.2 N to 6.0 N, while raw red dice firmness increased from 3.4 N to 5.1 N ($P<0.05$). This agrees with similar results found by previous investigators (Floros *et al.* 1992; Barrett and Garcia 1997). Floros *et al.* (1992) found optimum concentration and dipping

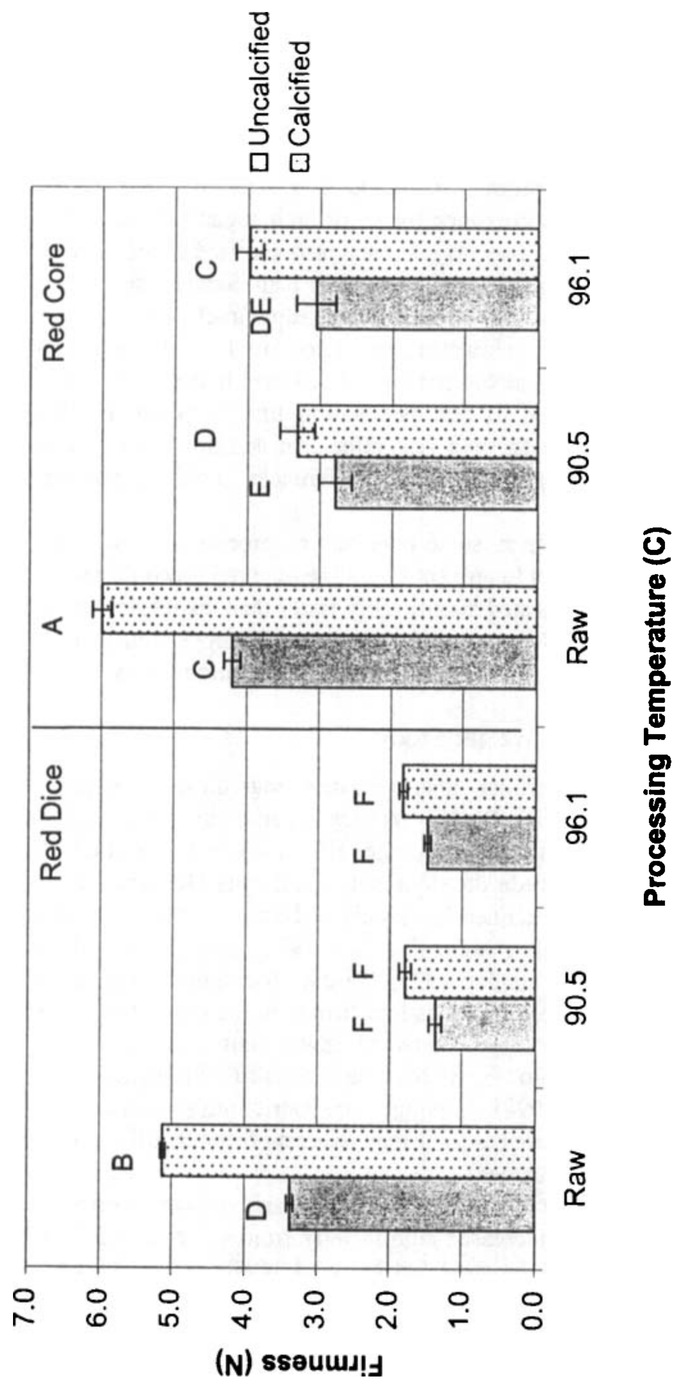


FIG. 2. FIRMNESS OF UNCALCIFIED AND CALCIFIED RAW AND PROCESSED DICED TOMATOES (1.91 CM DICE SIZE) (LSD 95% confidence level).

time for raw 1.27 cm diced tomatoes to be 0.43% calcium chloride for 3.5 min, while Barrett and Garcia (1997) determined the best conditions for 1.27 cm dice to be 0.5% calcium chloride dips for 3 min.

Processing at high temperatures (90.5 and 96.1C) resulted in a significant decrease from initial raw firmness in both dice types (Fig. 2). This is most likely due to a loss in cell hydrostatic pressure and turgor (Bourne 1989). Calcified red cores were significantly firmer than uncalcified cores after processing at high temperatures ($P<0.05$); however this difference was not observed in red dice. This may be due to the greater amount of parenchymatous than locular tissue in red cores, enabling calcium to bind to demethoxylated pectic acid chains thus firming the tissue. Locular material did not appear to firm after dipping in calcium solution. The degree of initial raw firmness retained in the samples following calcification and processing were: red dice 53% and red core 74% after 90.5C processing; red dice 54% and red core 95% after 96.1C processing (Fig. 2).

Previous findings by the authors (Ma and Barrett 2001) showed that red tomatoes that were mechanically diced to 1.27 cm retained 60% of their initial raw firmness at 88C and 50% at 92C. The higher firmness retained in the present study may be because tomatoes were hand diced, while the previous study used a varied assortment of red dice and cores from a mechanical dicer. Huang and Bourne (1983) found that commercially processed fruit products typically retain only 3-16% of raw fruit firmness. However, this may have been due to the use of different processing times, temperatures, methods, and calcification. Commercially canned fruits and vegetables are typically retorted for 40-60 min, which is a more severe heat treatment than that used in the present study. There was no significant difference ($P<0.05$) in firmness between the two calcified dice sizes after processing at 90.5 or 96.1C (Fig. 3).

There was no significant differences in tomato firmness due to processing medium, e.g. water versus tomato juice ($P<0.05$). Average red dice firmness after processing at 90.5C was 1.8 N in water and 1.7 N in juice. Average red core firmness after processing at 90.5C was 3.3 N in water and 3.2 N in juice.

There were also no significant differences in red dice firmness levels after cooling in water versus juice (Fig. 4). This indicates to processors that the processing and cooling mediums used in this study have no significant impact on firmness of the final diced tomato product.

In addition, calcification and processing at either 90.5 or 96.1C had no significant effect on diced tomato drained weight for either dice type ($P<0.05$) (Fig. 5). Average drained weight ranged from 75-88%.

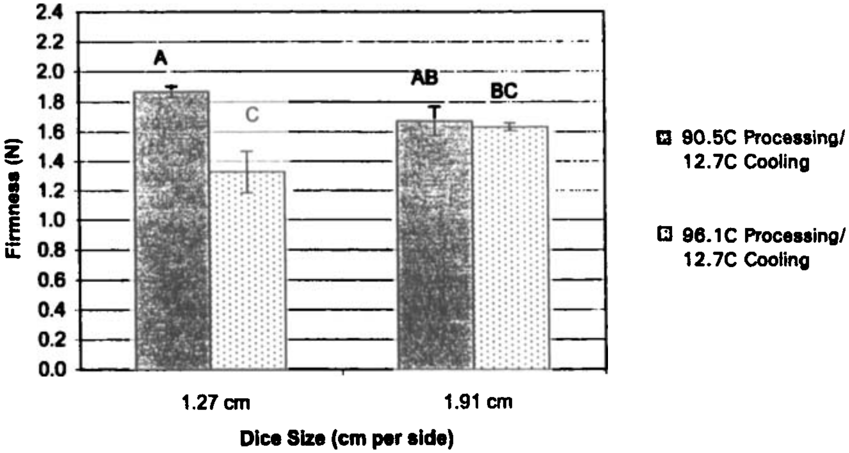


FIG. 3. COMPARISON OF FIRMNESS BETWEEN RED TOMATOES OF TWO DICE SIZES PROCESSED AND COOLED IN TOMATO JUICE (LSD 95% confidence level).

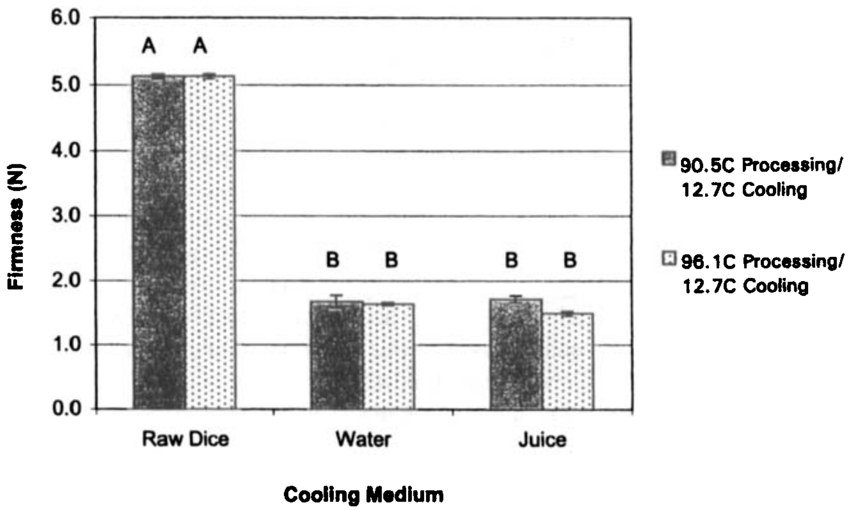


FIG. 4. COOLING MEDIUM EFFECT ON FIRMNESS OF 1.91 CM DICED TOMATOES AFTER PROCESSING IN JUICE (LSD 95% confidence level).

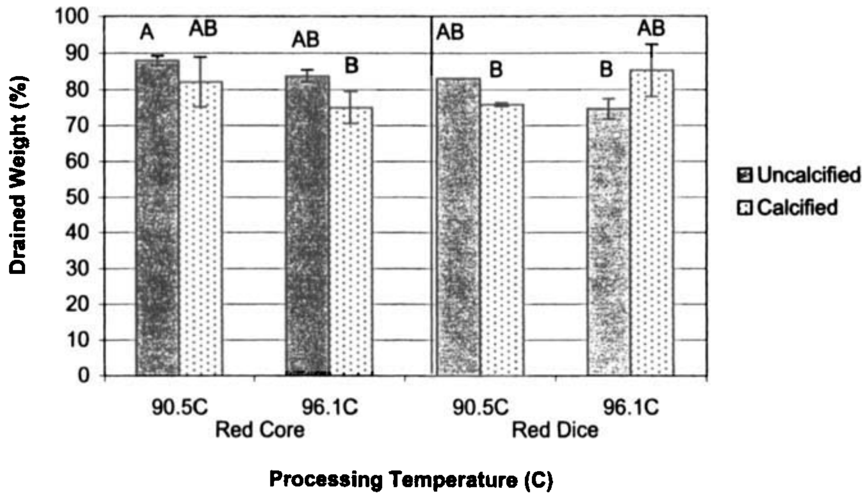


FIG. 5. DRAINED WEIGHT OF PROCESSED RED DICED TOMATOES (LSD 95% confidence level).

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