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Variations in physical-chemical properties of tomato suspensions from industrial processing

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ABSTRACT

Industrial tomato processing begins with a "break" step, in which the tomatoes are subjected to a thermal treatment to disrupt the fruit consistency: a low temperature break (cold break, CB; 60–77 °C) yields fresher products, whereas a high temperature break (hot break, HB; > 90 °C) is used for higher viscosity products. The HB process is believed to destroy most pectolytic enzyme activity, thereby preserving the pectic matrix. This study assessed the physical/chemical basis for viscosity differences in HB and CB products. Based on serum replacement and subsequent viscosity assays, it was determined that the solubilized pectin in the serum was not a significant factor. Instead, it appears that the different temperature regimes result in the formation of particulate material, or pulp, with different rheological properties. The particle size and viscoelastic properties of the pulp differed between the two break products, indicating that differences in the particle phase may determine the viscosity differences between HB and CB products. The HB particulate material exhibited a high degree of elasticity, as indicated by its large measured storage modulus whereas the CB pulp was composed of particles having a more viscous behavior (lower storage modulus and comparable with measured loss modulus).

1. Introduction

Tomato varieties used for processing have a high soluble solids content, which improves the characteristics of the final products (Moelants et al., 2013, 2014a). The most common form of processed tomato products is an industrial form of tomato "paste," which is a dispersion of solid particles (i.e. pulp) in an aqueous phase (serum) after removal of skin and seeds. It has a minimum of 24% (g/100 g) natural soluble solids (USDA., 1977). These products are stored in bulk, and can be reconstituted up to 18 months later in various products, such as soups and sauces (Bond, 2017).

While color and flavor are important quality attributes of tomato products, consistency (i.e. viscosity) is a very important parameter for determining the overall quality and acceptability of products such as tomato juice, paste and sauces. The initial viscosity of a tomato product is related to its economic value, as fewer tomatoes are required to produce a viscous paste if the tomatoes themselves have a higher viscosity (Thakur, Singh, & Nelson, 1996). Viscosity is further influenced by a number of intrinsic factors, including tomato variety, growing conditions, and fruit maturity (Gould, 1992). In a ripe tomato fruit, more than 90% of the fresh weight is water (Thakur et al., 1996). Degradation of starch, resulting in the production of glucose and fructose, is one of the major changes during ripening, along with minor changes in composition. These changes affect the overall texture, color and flavor of the fruit (Grierson et al., 1986).

The first step in producing industrial tomato paste is the "break" stage, which plays a vital role in determining the quality of final products (Nelson & Hoff, 1969). There has been extensive studies on the influence of processing steps on the rheological properties of tomato products (Anthon, Diaz, & Barrett, 2008; Bayod & Tornberg, 2011; Bayod, Mansson, Innings, Bergenstahl, & Tornberg, 2007; Diaz, Anthon, & Barrett, 2009; Moelants et al., 2014b; Sanchez, Valencia, Ciruelos, Latorre, & Gallegos, 2003; Sharma, LeMaguer, Liptay, & Poysa, 1996; Valencia et al., 2002). The whole fruits are chopped or crushed and immediately subjected to a heat treatment. In the hot-break (HB) process, the crushed material is pumped into a heat exchanger and heated rapidly to a temperature range from 82.2 °C (180 °F) to 104.4 °C (220 °F). In contrast, for the cold-break (CB) procedure, crushed tomatoes are further processed at a temperature range of 66 °C (150 °F) to 77 °C (170 °F), and then transferred to a holding-tank, where they are held for a period ranging from seconds to several minutes (Gould, 1983). Two main objectives of these break steps are the partial or full

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inactivation of degradative enzymes, such as polygalacturonase (PG) and pectin methylesterase (PME), and the softening of tissues to facilitate further processing (Marsh, Buhlert, & Leonard, 1980).

The overall viscosity of the initial processing product increases with the temperature regime used in the break process (Gould, 1974, 1992; Hand, Moyer, Ransford, Hening, & Whittenberger, 1955; Hsu, 2008; Luh & Daoud, 1971; Thakur et al., 1996). The relatively low viscosity of CB products has been attributed to the remaining activity of pectolytic enzymes that catalyze an extensive breakdown of the pectic matrix and release of water-soluble oligomers. In contrast, HB conditions have been proposed to more efficiently inactivate pectolytic enzymes. However, recent research has shown that the break-down and solubilization of pectin is limited in its effect on product composition (Chong, Simsek, & Reuhs, 2009; Chong, Simsek, & Reuhs, 2014; Wu et al., 2018 In preparation), and therefore its impact on the suspension viscosity. The goal of this research was to investigate the basis of viscosity differences in industrial processing products, from HB or CB conditions, focusing on the rheological behavior of tomato sera, separated pulp particles, and overall tomato products, in relation to the chemical composition of the HB and CB tomato sera described in previous publications (Chong et al., 2009, 2014).

2. Materials and methods

2.1. Initial tomato product preparation (from industry)

The tomato samples were supplied by Red Gold Inc. (Elwood, Indiana facility) during the growing season. The samples obtained for this study were collected immediately after breaking, so that possible interferences due to subsequent processing treatments were eliminated. The samples contained no remnants of the skin or seeds. The processing temperature for HB was 93.3 °C, and for CB 77.2 °C. During the production of tomato samples, circa 25 kg of each tomato product (HB and CB) were collected immediately after the tomatoes were chopped and heated, and before they passed through the finisher. Samples were transported to the laboratory in iced containers and stored in a cold room (4 °C) overnight. Afterwards, HB and CB tomato sample aliquots were stored at −20 °C. The frozen samples were thawed to room temperature for further analysis.

2.2. Tomato serum and precipitate preparation

The crude preparations were then analyzed for viscosity comparisons. In addition, aliquots of the tomato preparations were concentrated using roto-evaporation at 40 °C to remove approximately 50% of the water; this was followed by additional viscosity analyses. Subsequent characterization of the properties of tomato pulp and sera required centrifugation of the original tomato products at 12,800 × g (8505 rpm) at 4 °C for 30 min (Beckman Coulter Inc., Fullerton, CA), for separation of the supernatant and the separated pulp particles. The supernatant from HB and CB samples were designated as HB or CB sera. In order to analyze the serum contribution to the tomato products overall viscosity, the supernatants of HB and CB juices were exchanged; the supernatant of HB tomato product was substituted by the same weight of the supernatant from the CB product, and vice versa. In addition, in subsequent experiments, the supernatant was removed by centrifugation and replaced with same weight of distilled-deionized water. In all samples, the mixture was then stirred to form a uniform pulp suspension.

2.3. Pulp particles weight ratio and solid content

The pulp particles weight ratio was measured as per Takada and Nelson (Takada & Nelson, 1983). Approximately 300 g of samples were placed into pre-weighed Nalgene® centrifuge bottles, and centrifuged as described in section Tomato serum and precipitate preparation. The weight of the bottle and the total weight of bottle and sample were recorded before centrifugation. Following centrifugation, the supernatant was removed and the bottle was allowed to drain for 3 min to remove excess liquid. The bottle with the separated pulp particles were then weighed and the pulp particle ratio was determined.

Samples were transferred to the pre-weighed drying dishes and dried for 12 h at 60 °C in the vacuum oven. The total weight of dish and sample was recorded before and after drying. The percent of solids of the samples were determined.

2.4. Brix

Brix of tomato product was measured by an Abbe refractometer at room temperature. A drop of filtered tomato preparation (or serum) was placed on to the glass prism. The viewing field was adjusted to obtain the best definition for the light and dark areas, and the Brix value was noted.

2.5. Viscosity

The viscosity of tomato sera was determined with a Cannon-Fenske Opaque viscometer (size 50, CANNON Instrument Company, Stage College, PA). The viscometer was kept in a vertical position in a 40 °C bath. A 10 ml sample was pipetted into the viscometer. The efflux time, in seconds, for the fluid to pass through the demarcation lines was recorded for calculating the kinematic viscosity. The result are reported in cSt.

The viscosity of tomato sera, tomato products, exchanged tomato samples, and pulp suspensions were also measured with an AR/G2 Rheometer (TA Instruments, New Castle, DE) using a cup and bob geometry (cup radius 15 mm, bob radius of 14 mm and height of 42 mm). The sample viscosity (Pa.s) was measured as a function of shear rates in the range 0.01–500 1/s at 25 °C and the viscosity profiles for different samples are presented for comparison. The viscosity for the tomato sera were described by the Power-Law model (Rao, 2007).

The viscoelastic properties of tomato pulp were tested using a 40 mm parallel plates geometry and a 1500 μm gap in the AR/G2 rheometer. A frequency sweep test in the range 0.01–100 Hz was performed at 25 °C with a 5% strain, which was in the linear viscoelastic range (determined previously). Storage G' (Pa) and loss G" (Pa) moduli were recorded.

2.6. Particle size analysis

The particle size distribution (PSD) in tomato pulp suspension was measured using a Mastersizer 2000 static light scattering instrument (Malvern Instruments Ltd, Malvern, UK). Samples were diluted by an approximate factor of 800 prior to measurement to avoid multiple scattering effects. The instrument software (Mastersizer 2000, version 5.60) was used to calculate PSD based on the Fraunhofer optical model, as well as the area based average ($d_{3,2}$) and volume-based average ($d_{4,3}$) diameters of the particles.

2.7. Statistical analysis

All the measurements were performed in triplicate, unless otherwise stated. A p-value of less than 0.05 was considered significant for all analysis of variance and t-tests in the study were carried using OriginPro (version 8.0773, OriginLab Corp., Northampton, MA).

3. Results & discussion

3.1. General properties

The physical properties of tomato sera processed under HB and CB conditions are presented in Table 1. As with other studies (Moresi &