Influence of Pre-drying Treatments on Quality and Safety of Sun-dried Tomatoes. Part I: Use of Steam Blanching, Boiling Brine Blanching, and Dips in Salt or Sodium Metabisulfite

GUADALUPE LATAPI AND DIANE M. BARRETT

ABSTRACT: The effect of various pre-drying treatments on the subsequent quality of sun-dried tomatoes was evaluated by determining moisture, color, rehydration ratio, mold, yeast, sulfur dioxide, and/or salt content. The 4 pre-drying treatments under investigation were (1) steam blanching or (2) boiling brine blanching, followed by gas sulfuring and (3) dipping in either salt (0%, 10%, 15%, 20%) or (4) sodium metabisulfite (0%, 4%, 6%, 8%) for 0, 2.5, 5.0, and 7.5 min. Neither blanching pretreatment improved the quality of the dried product. Salt dipping resulted in significant differences in rehydration ratio, yeast, and salt. The most effective salt pretreatment conditions were a 10% or 15% salt dip for 5 min. Sodium metabisulfite dipping caused significant differences in rehydration ratio, yeast, color, and sulfur dioxide. Dipping tomatoes in 6% or 8% sodium metabisulfite for 5 min before drying established the best color. The 9 pretreatments studied were also evaluated for storage stability at 25 °C and 30% to 34% relative humidity for 3 mo.

Keywords: tomato, dehydration, sun-drying, salt, metabisulfite

Introduction

In 2001, the United States produced an estimated 2720 metric tons of sun-dried tomatoes valued at $16 million (TDF 1999). During the same year, the United States imported about 2622 metric tons of sun-dried tomatoes valued at $8.1 million (USDA 2002). This is not surprising considering their importance as an ingredient in the food industry, their acceptance by the food service sector, and their convenience of transport and storage. Sun-dried tomatoes are ideal for meal enhancement and quick preparation cooking and may be used all year.

Tomatoes may be dried using either solar energy or mechanical systems. Traditional sun-drying is a slow process compared with other drying methods, but it is said to give dried tomatoes their distinctive quality. Sun-drying allows flavors to concentrate, preventing loss of volatiles and undesirable caramelization of natural tomato sugars, thus avoiding sweet or burnt aftertaste and undesirable brownish color, which may result from using other methods (TDF 1999; Valley Sun 2000). Sun-drying enhances good initial color and texture, as well as translucency and sheen (Mrak and others 1946).

California, Turkey, Morocco, Mexico, Chile, Spain, and Italy, among others, currently supply the North American industrial market (Ecom 1997). Turkey supplies the largest volume with an estimated 55% of total imports for 2001 (FIR 2002). Increasingly, consumers demand processed products of consistent quality that retain more of their original characteristics (Nijhuis and others 1998). During sun-drying, quality losses may result from color degradation (browning, caused by enzymatic and nonenzymatic reactions), microbial growth (mostly caused by molds and yeast), poor rehydration (caused by injuries to the material during pretreatment and drying) (Okos and others 1992; Lewicki 1998), along with nutritional losses of ascorbic acid and lycopene.

In the sun-dried tomato industry, sulfite is still the most commonly used additive because of its multiple functions. Sulfite acts primarily as (1) an inhibitor of enzymatic and nonenymatic browning, (2) an antioxidant preventing oxidative spoilage (oxygen scavenger and reducing agent), (3) an inhibitor of some enzymes such as proteases, oxidases, peroxidases, (4) an antimicrobial, and (5) a fungistat (Ough 1993), and (6) by plasmolyzing cells (Gould and Russell 1991), which facilitate drying.

Traditionally, tomatoes are sun-dried after a pretreatment with sulfur dioxide, in closed chambers either by burning sulfur or gassing with sulfur from a cylinder (Cal Sun Dry 1997; TDF 1999; Valley Sun 2000). Another method for introducing sulfur dioxide into the tomato is by dipping in sodium metabisulfite solutions (Pazyr and others 1996). Salt may also be used for curing sun-dried tomatoes when the use of sulfites is not desired (Ecom 1997). Sun drying requires 7 to 12 d, and results in a product with typically 12% to 24% moisture and robust taste. Sun-dried tomatoes darken during storage, which is typically 9 to 12 mo (Ecom 1997).

Scientific literature on methods for improving the quality of sun-dried tomatoes through modification of the traditional process or incorporation of pretreatments is limited and variable.

Blanching is one of the most widely used pretreatments in the dehydration of fruits and vegetables (McBean and others 1964). It is used to upgrade the quality of the final dried product, but the effectiveness of the combination of blanching and sulfuring before sun-drying tomatoes has not been investigated.

To date, there have been no published studies comparing the

MS 20040374 Submitted 6/7/04, Revised 6/7/05, Accepted 9/21/05. *The authors are with Dept. of Food Science and Technology, Univ. of California, Davis, Davis, CA 95616-8589. Direct inquiries to author Barrett (E-mail: dmbarrett@ucdavis.edu).*

Table 1—Experimental design for studies on effects of pre-drying treatments on sun-dried tomato quality and safety

Trial dates:	Trial 1 – 8/03/01 to 8/09/01 Trial 2 – 8/14/01 to 8/20/01 Trial 3 – 8/28/01 to 9/4/01
Evaluation:	moisture, color, mold, yeast, rehydration ratio, SO_2, and salt content

Samples analyzed following drying; selected samples after 3 mo of storage.

Pre-drying treatments	Specific conditions
1. Steam blanching and sulfuring	100 °C for 0, 20, 40, 60 s, 2.3 kg (5 lb) SO_2
2. Boiling brine and sulfuring	0%, 2.5%, 5.0%, and 7.5% salt 100 °C for 40 s, 2.3 kg (5 lb) SO_2
3. Salt dipping	0%, 10%, 15%, and 20% salt 25 °C for 0, 2.5, 5.0, and 7.5 min
4. Sodium metabisulfite dipping	0%, 4%, 6%, and 8% $Na_2S_2O_5$ 25 °C for 0, 2.5, 5.0, and 7.5 min

effects of sulfur dioxide gas and sodium metabisulfite dipping treatments on quality parameters of sun-dried tomatoes. The objective of this study is to evaluate the effects of 4 pretreatments on various quality and safety parameters, including: final moisture content, color, rehydration ratio, mold and yeast count, sulfur dioxide content, and/or salt content. Pretreatments evaluated are (1) steam blanching followed by direct gas sulfuring, (2) blanching in boiling brine followed by direct gas sulfuring, (3) dipping in salt, and (4) dipping in sodium metabisulfite. Pretreated products with the best quality and safety parameters after sun drying were stored for 3 mo at 25 °C and 30% to 34% relative humidity and then evaluated for qualitative changes.

Materials and Methods

Raw materials and pre-drying treatments

The Campbell Soup Supply Co. (Dixon, Calif., U.S.A.) supplied approximately 160 kg of red ripe Halley 3155 tomatoes (Orsetti Seed Co., Hollister, Calif., U.S.A.). After being transported to the UC Davis Food Processing Laboratory, the tomatoes were sorted and washed with chlorinated (5 ppm) water at 25 °C. Tomatoes were cut into halves from stem scar to blossom end with a stainless-steel knife. The 160-kg batch was divided randomly into 4 groups (2 groups of 20 kg and 2 of 60 kg) to which the pre-drying treatments described subsequently were applied. Table 1 lists the pre-drying treatments investigated in this article (Part I).

Steam blanching and sulfuring

Twenty kilograms of tomatoes were divided randomly into 4 equally sized batches that were steam blanched (100 °C) at atmospheric pressure for 0, 20, 40, and 60 s, respectively. After steam blanching, the tomatoes were cooled and drained on a sieve for a few minutes. Approximately 120 tomato halves were spread in a single layer on 61- × 122-cm wooden trays and weighed. Trays were stacked in a 1.70 m^3 wooden box, which was closed tightly and covered with plastic to minimize leakage. Sulfur dioxide gas (2.3 kg or 5 lb) was injected through a tube into the box and the gas cylinder was mounted on a scale so that gas use could be accurately determined. The trays were kept in the sealed box for 12 h.

Boiling brine blanching and sulfuring

Twenty kilograms of tomatoes was divided randomly into 4 equally sized batches that were blanched in boiling brine with either a 0%, 2.5%, 5%, or 7.5% salt concentration for 40 s. The control was dipped in boiling, unsalted water for 40 s. The tomato-to-dipping solution ratio was 1:3. Brine-blanched tomatoes were sulfured using the process described previously.

Salt dipping

A 60-kg batch of tomatoes were randomly divided into 13 batches to accomplish all possible combinations of dipping for 0, 2.5, 5, or 7.5 min in salt concentrations of 0%,10%, 15%, or 20%. Thirteen batches, rather than 16, were sufficient for the experimental design of 4 (dipping times) × 4 (salt concentrations) because only 1 control (undipped; time 0 × 0 salt concentration) was needed for the 3 dipped batches. The tomato-to-dipping solution ratio was 1:3. The solutions were mixed continuously during dipping; tomato halves were drained, spread in a single layer on 61- × 122-cm wooden trays, and weighed.

Sodium metabisulfite dipping

Sixty kilograms of tomatoes were randomly divided into 13 batches to meet all possible combinations of dipping for 0, 2.5, 5, or 7.5 min with 0%, 4%, 6%, or 8% sodium metabisulfite. The tomato-to-dipping solution ratio was 1:3, and tomatoes were mixed, drained, and weighed as described previously.

Sun-drying

All the trays from the 4 pre-drying treatments were placed on the roof of the Food Processing Laboratory within approximately 1 h of pretreatment and exposed to direct sunlight. Outside temperature and relative humidity were monitored with an Omega data logger (Omega Technologies Co., Model OM-550, Stamford, Conn., U.S.A.) and compared (Table 2) to weather data retrieved from the web site of the Univ. of California Statewide Integrated Pest Management Project (UC IPM 2001).

Dried tomatoes were packed into polyethylene-sealed bags and stored at –20 °C. The whole sun-drying experiment was carried out 3 times. The length of each drying trial was determined from previous investigations, and each trial was approximately the same length (7 to 8 d). After drying, 4 sets of representative samples were taken randomly from each batch. One set was analyzed for moisture content (10 g), a 2nd for rehydration ratio and color (40 g), a 3rd for mold and yeast count (50 g), and a 4th for storage at 25 °C and 30% to 34% relative humidity for 3 mo (100 g). Extra sets of samples were taken for sulfur dioxide (50 g) and salt content (40 g) from the batches that required such analyses. One average dried tomato half weighed approximately 3.5 g.

Storage

Samples of approximately 100 g from each combination of the 4 pre-drying treatments were stored at 25 °C and 30% to 34% relative humidity for 3 mo in polyethylene sealed bags (17.8 cm × 20.3 cm and 2.7 mil thickness). After 3 mo, the same analyses that were carried out before storage were made, but only on selected samples. Samples with the highest quality immediately after sun-drying (determined by lowest hue angles, highest rehydration ratio, and highest sulfur dioxide content for sulfured samples) were chosen for additional analysis after storage.

Analytical methods

Moisture content (% moisture w/w) was determined using the vacuum oven method as per AOAC (1984). Triplicate determinations were carried out per sample. The color of the sun-dried tomatoes was measured using a Minolta colorimeter, Model CR-200 (Ramsey, N.J., U.S.A.). In the CIE color system, a describes the intensity of red color ($a > 0$); b the intensity of yellow ($b > 0$), L the lightness (black = 0,

Table 2—Weather conditions during the 3 drying trials used for sun-drying tomatoes[a]

Replicate nr/date (mm-dd-yy)	Temperature[b] (°C)		Relative humidity[c]		Solar radiation[e]	Wind speed[d]		Degree-days
	Max	Min	Max	Min	(LY)	Direction	Miles/h	(heat units)
Trial 1								
08-03-01	31.7	12.8	86.9	33.6	336	S	4	17.85
08-04-01	30.6	14.4	86.2	34.5	326	S	4	18.1
08-05-01	32.8	13.3	84.6	23.7	329	S	2	18.65
08-06-01	35.0	11.7	87.7	20.3	330	S	2	18.95
08-07-01	37.2	14.4	83.7	19.4	315	S	2	21.4
08-08-01	38.9	16.7	76.5	18.2	315	S	2	23.4
08-09-01	32.8	15.6	75.9	27.7	317	S	4	19.8
								Accumulated degree-days[f] 138.15
Trial 2								
08-14-01	33.9	9.4	88.9	18.0	325	S	2	17.25
08-15-01	33.9	10.0	89.7	19.0	319	SE	2	17.55
08-16-01	36.1	10.0	95.6	15.5	322	S	2	18.65
08-17-01	37.2	13.3	84.1	16.4	310	S	2	20.85
08-18-01	33.9	12.2	96.4	22.6	309	SE	2	18.65
08-19-01	33.3	12.8	80.4	24.3	311	S	2	18.65
08-20-01	26.1	12.8	85.8	44.0	301	S	4	15.05
								Accumulated degree-days 126.65
Trial 3								
08-28-01	37.8	14.4	75.8	18.7	293	S	3	21.70
08-29-01	32.8	13.3	80.8	29.6	284	S	3	18.65
08-30-01	26.1	13.9	85.8	47.5	280	S	4	15.60
08-31-01	31.1	11.7	88.9	33.0	273	S	2	17.00
09-1-01	32.2	11.7	95.2	24.6	280	S	2	17.55
09-2-01	34.4	13.9	75.9	16.5	283	S	2	19.75
09-3-01	35.0	13.9	81.8	16.3	279	S	2	20.05
09-4-01	35.6	13.9	79.9	14.0	279	S	3	20.35
								Accumulated degree-days 150.65

[a]Data from California Weather Databases. Univ. of California. Statewide Integrated Pest Management Project. All data were retrieved from station Davis A (CIMIS nr 6, Davis).
[b]Air temperature: daily max/min measured at 1.5 m.
[c]Humidity: daily max/min relative humidity measured at 1.5 m.
[d]Wind speed and direction: daily average measured at 2 m.
[e]Solar radiation: daily global radiation measured by Licor pyranometer at 2 m.
[f]Accumulated degree-days is the sum of all the degree-days for each replicate or drying period.

white = 100); and hue angle (Hue° = $\tan^{-1} b/a$) the hue of the sample (red = 0, yellow = 90). Thirty replicates were carried out per 40 g of each sample, and color was reported as hue angle. The optimum hue angle for sun-dried tomatoes was considered the value nearest to that hue angle (range, 24 to 28) of a fresh tomato.

A representative sample of 50 g was selected randomly, placed in a sterile bag, and sent to a private laboratory (Silliker Laboratories of California in Modesto, Calif., U.S.A.) for mold and yeast counts according to the reference method of the 7th edition of FDA-BAM, (AOAC 1988). The interpretation of viable yeast and mold counts often is difficult because background data on expected and excessive levels of these microorganisms have not been established in many foods. For this study, the limits of mold count per gram used were taken from the recommended sampling plan and microbiological limits for sun-dried fruit given by the Intl. Commission on Microbiological Specifications for Foods (ICMSF 1974). Those limits are as follows:

$$\text{Mold: limits per g: m} = 10^2/\text{g; M} = 10^4/\text{g}$$

$$\text{Osmophilic yeast: limits per g: m} = 10^2/\text{g; M} = 10^3/\text{g}$$

where m represents an acceptable level, and M is the maximum allowable concentration. Osmophilic yeasts are of no public health significance, but they are responsible for spoilage and development of off or fermented odors, which limit shelf life (Vanderzant and Splittstoesser 1992).

Duplicate determinations of the rehydration ratio and sulfur dioxide and salt content were carried out. For the rehydration ratio, 20 g of dried tomato halves were submerged in distilled water at room temperature (24 ±2 °C) for 24 h (Levi and others 1988) with a product-to-water ratio of 1:8 (Kareem and others 1978). The samples were drained for 2 to 3 min, and adhering water was absorbed onto tissue paper, then samples were weighed again. The index used to express rehydration of dry plant tissues is a ratio of weight after rehydration/initial weight (Lewicki 1998). Total sulfur dioxide (ppm dry weight basis) was determined using the modified Reith Williams Method (FAO 1986). Salt content (% sodium chloride dry weight) was determined according to Pearson (1973).

Statistical analyses

After drying, the corresponding analyses were carried out for each pre-drying treatment. In some cases, each analysis had lab replicates that were averaged and called a "batch average." Because the entire experiment was replicated 3 times (3 drying trials), the mean of the 3 batch averages was used as the mean value presented in the statistical results.

The data for the steam blanching and boiling brine blanching trials was analyzed using piecewise linear regression (Neter and others 1996) of the moisture content, rehydration ratio, mold and yeast count, color value, sulfur dioxide, and content. The model that resulted for steam blanching has 2 factors, for example, time and replicates (drying trials), with 2 levels for time (time 0 or control, and time 20, 40, or 60 s), and 3 levels for replicates. Significance was

Table 3—Effect of steam blanching pretreatment for various times on final moisture, sulfur dioxide, and mold in sun-dried tomatoes

	Final moisture (% wet wt.)			SO_2 (ppm dry wt.)			Mold (colony-forming units/g)		
Steam blanch (s)	Trial 1	2	3	Trial 1	2	3	Trial 1	2	3
0	17.69	21.00	8.74	2507	2510	2314	30	50	30
20	14.61	20.45	8.06	1766	1951	1766	10	30	20
40	14.51	18.56	7.89	1712	1768	1546	20	20	20
60	11.77	14.90	7.50	1605	1636	1522	10	20	20

defined at $P < 0.05$. For analysis of the boiling brine data, 2 factors were used, for example, concentration and replicates (drying trials) with 2 levels for concentration (concentration 0 or control, and concentration 2.5%, 5%, or 7.5%), and 3 levels for replicates. Significance was defined at $P < 0.05$.

An analysis of variance (ANOVA) was performed on each quality parameter analyzed in the salt and sodium metabisulfite dipping trials. Tukey's test was used for testing significant differences between means with a confidence level of 95%. Logarithm transformations (log) on mold and yeast count (colony-forming units [CFU]/g) were necessary to achieve a normal distribution (Neter and others 1996).

A paired t test (2-tailed) was used for comparing treatments before and after 3 mo of storage.

All statistical analyses were carried out with the General Linear Model (GLM) procedure of SAS (SAS Inst., Cary, N.C., U.S.A.).

Results and Discussion

Steam blanching pretreatment

Preliminary studies indicated that steam blanching at 20 and 40 s did not produce any visible change in the flesh or peels of the tomato halves. At 60 s, however, the skin began to loosen, and the flesh softened moderately. Steam blanching for more than 60 s caused tomatoes to collapse, the skin to separate, and the flesh to cook. Therefore, the selected range of time for steam blanching was 20, 40, and 60 s.

With reference to moisture content, the control (no steam blanching before sulfuring and drying) and all the steam blanching times differed from one another. Table 3 illustrates that moisture content decreases as steam blanching time increases. This decrease in moisture content could be due to the softening and partial cooking of the tissues, rendering the cell membranes more permeable to moisture transfer (Brenndorfer and others 1987). Loss of cellular fluids during the blanching pretreatment may have resulted in greater moisture loss during subsequent sun-drying.

There were significant differences ($P < 0.05$) in moisture content within the 3 drying trials (replicates), which may be explained by the different environmental conditions that existed during each trial (Table 2). The final moisture values for the 3 drying trials ranged from 11.8% to 17.7% for the 1st trial, 14.9% to 21% for the s trial, and 7.5% to 8.7% for the 3rd trial (Table 3). During the 2nd drying trial, the temperature dropped to its lowest at night, and relative humidity was higher during the last 3 d of drying when compared with the other 2 replicates. The 2nd trial had the lowest accumulated degree-days (126.65) of all drying periods, meaning there was less heat in the atmosphere (Table 2), which resulted in higher moisture content for the sun-dried tomatoes from this 2nd replicate.

Steam blanching times (20, 40, and 60 s) had an effect on decreasing the final sulfur dioxide content in the sun-dried tomatoes from an average (over 3 trials) of 2444 ppm to 1829, 1675, and 1587 ppm, respectively (Table 3). These results are consistent with sulfur dioxide studies carried out on other fruit (peaches, apricots, and pears), in which steam blanching notably reduced sulfur dioxide absorption (McBean and others 1964; Baloch and others 1987). According to these authors, blanching causes cellular structure changes in fruit tissue that presumably lead to the blocking of intercellular pathways for gas entry, thereby affecting diffusion of gas into the tissue.

All mold and yeast counts were under allowable limits (10^4/g and 10^3/g, respectively) set by the Intl. Commission for Microbiological Specifications for Foods. Yeast counts were the same for both control and treated samples (10 CFU/g). Steam blanching decreased mold growth compared with the control (Table 3), but there were no significant differences between the various steam blanching times. The use of sulfur dioxide alone was enough to maintain mold count under allowable limits.

In general, all samples had an intense red color (data not shown). Among its multiple functions, sulfur dioxide prevents discoloration and browning (Gould and Russell 1991). Steam blanching before sulfuring decreased sulfur dioxide content and consequently did not have an effect on improving color when compared with the control.

The rehydration ratio of the sun-dried tomatoes (data not shown) was not improved with a steam blanching pretreatment before sulfuring. Compared with the control, raw material properties did not improve when steam-blanched, sun-dried tomatoes were rehydrated.

After sun-drying, tomatoes that were steam blanched before sulfuring had no comparative advantage over those that were not blanched. Heat treatment loosened the skin, causing it to crack and separate. Halves lost most of their seeds and locular juice in drying. As a result of blanching, some of the halves filled with liquid, which caused problems during tray movement because the juice dripped out, causing the dried tomatoes to flatten and stick to the trays and consequently tear during removal. These disadvantages are consistent with studies of steam blanching before dehydration reported by Culpepper and others (1948) for tomatoes and by Chace and others (1933) for apricots.

Boiling brine blanch pretreatment

Blanching in boiling brine for more than 40 s caused the tomatoes to collapse, the skin to crack and separate, and the flesh to cook. Therefore, the selected time for blanching was 40 s. The control used in this experiment was blanched in boiling water before sulfuring. In the steam blanching portion of this project (described previously), an unblanched control was used and may serve as another point of reference. For all quality measurements except salt content, neither of the 2 variables (concentration 0% and concentrations 2.5%, 5%, and 7.5%) were significant ($P > 0.05$), implying no linear difference between any treatment level (data not shown).

There was a significant linear relationship between salt concentration in the brine and salt content in the dried product (data not shown). As brine concentration increased, salt content in the tomato also increased (data not shown). Salt uptake is favored by the use of high temperatures (that is, higher than 60 °C), which modify tissue characteristics (Torreggiani 1994).

After sun-drying, all tomatoes either blanched in boiling water (control) or boiling brine (pretreated) before sulfuring displayed the disadvantages described previously for steam-blanched tomatoes. Leaching of the slices was intensified by thermal treatment and increased the loss of seeds and pulp during drying due to adherence to the trays and consequent tearing during removal.

Salt dip pretreatment

Dipping time was not significant for color, rehydration ratio, or yeast count ($P > 0.05$), but was significant for salt content. Concentration of the dipping solution had a significant effect ($P < 0.05$) on yeast count and rehydration ratio. Dipping in salt solutions before sun-drying resulted in significant decreases ($P < 0.05$) in the yeast counts of sun-dried tomatoes (Figure 1). Salt is an effective antimicrobial because it can inactivate enzyme systems vital to the cell, slowing or stopping microbial growth (Robinson and others 2000). In untreated sun-dried tomatoes, yeast counts were 4.9 log CFU/g, exceeding allowable limits (10^3/g) and resulting in off or fermented odors with physical signs of spoilage. Yeast growth was reduced significantly (3.5 log CFU/g) when tomatoes were dipped in a 10% salt solution for 5 min before sun drying. There was an additional decrease to 2.2 log CFU/g when tomato halves were pretreated for 5 min in either 15% or 20% salt. The 15% and 20% salt treatments for 5 min, which were not significantly different, did not have fermented odors or show signs of spoilage when compared with either those dipped in 10% salt or the control.

Rehydration may be considered a measure of the injuries to the material caused by drying and treatments preceding dehydration (Okos and others 1992; Lewicki 1998). Thus, the higher the rehydration ratio, the less damage to the tissues caused by the drying process and the greater the product hydration. There was a significant difference ($P < 0.05$) in the rehydration ratio between treatments and the control (Figure 1). Tomatoes dipped in salt solutions had lower rehydration ratios, for example, between 2.50 and 2.66 compared with the control value of 3.11, implying lower quality than the control.

Color values ranged from hue angles of 35.7 to 37.7 (Figure 1), with the control having the highest value and both the 10% and 15% salt dips having equally low values, but these differences were not significant ($P < 0.05$). Salt dipping did not improve the color of sun-dried tomatoes, and in general, these tomatoes appeared to have a darker unattractive color, most likely due to browning reactions that were not prevented as in the other 3 pretreatments using sulfur dioxide.

Both concentration and time were significant ($P < 0.05$) factors for final salt content of the sun-dried tomatoes (data not shown). As dipping time and salt concentration increased, salt uptake also increased. Sun-dried tomatoes dipped in a 10% salt solution for 2.5 min reached a final salt content of 7.5% after drying. When dipping time was increased to 7.5 min at the same concentration, the final salt concentration in the dried tomatoes increased to 11.1%. When a 15% concentration was used with dipping time increased from 2.5 to 7.5 min, salt absorption increased from 10.2% to 14.2%. The recommended combinations of salt concentrations and dipping time to control yeast growth, but minimize the effect on color and rehydration ratio are either 10% or 15% salt for 5 min (Figure 1).

Sodium metabisulfite dip pretreatment

The analysis of variance shows that the overall test of significance was not significant for mold count ($P > 0.05$) (Table 4). Dipping time was not significant as a main effect for any of the response variables ($P > 0.05$) except sulfur dioxide content. The concentration of the dipping solution had a significant effect on sulfur dioxide content, color, rehydration ratio, and yeast count.

As dipping time and sodium metabisulfite concentration increased, sulfur dioxide absorption also increased (Figure 2). Sun-dried tomatoes dipped in 4% sodium metabisulfite for 2.5 min reached a sulfur dioxide content of 840 ppm, and this content increased about 55% to 1305 ppm when tomatoes were dipped for 7.5 min. At the other extreme, a 2.5 min dip in 8% $Na_2S_2O_5$ resulted in a concentration of 3106 ppm in the sun-dried fruit; when dipping time was extended to 7.5 min, this increased about 2.7-fold to 8631 ppm. Pazyr and others (1996) reported that the absorption of sulfur dioxide in sun-dried tomatoes increased as the concentration of the metabisulfite solution and dipping time increased. Sulfur dioxide content for sun-dried tomatoes in this study are similar to those given by Pazyr and others (1996), who found that tomatoes dipped for 2.5 and 10 min had residual sulfur dioxide contents of 2785 and 8395 ppm, respectively. These quantities are consistent with the linear relationship between concentration of metabisulfite solution and absorption of sulfur dioxide observed in apricots by Stafford and Bolin (1972) and carrots by Baloch and others (1987).

Significant differences in color were observed (Table 4) between metabisulfite concentrations ($P < 0.05$). As the concentration of

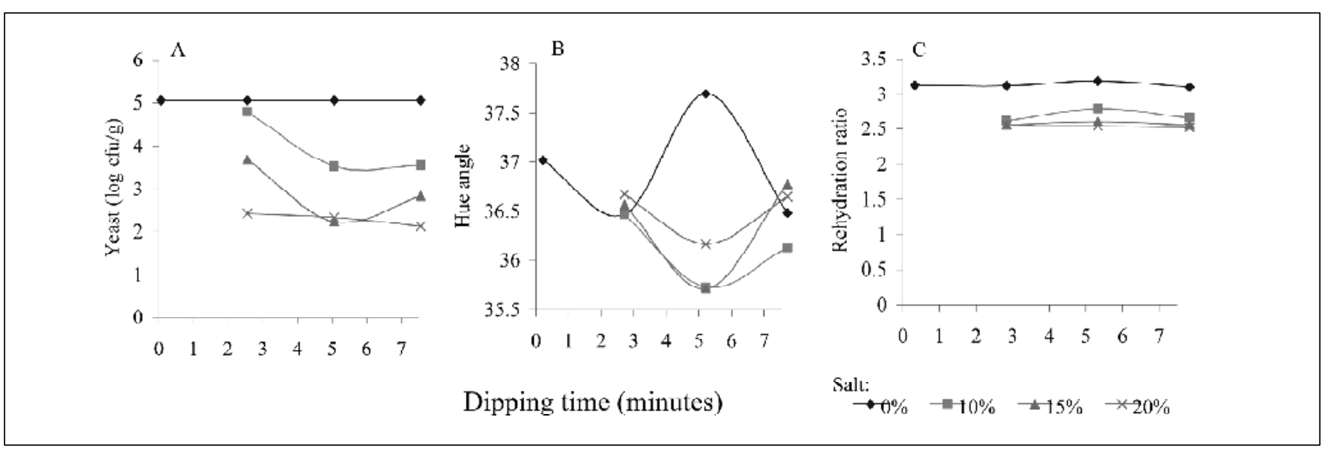

Figure 1—Effect of dipping time and salt concentration on (a) yeast count (log colony-forming units [CFU]/g), (b) hue angle, and (c) rehydration ratio of sun-dried tomatoes

Table 4—Effect of sodium metabisulfite concentration on moisture content, sulfur dioxide content, color, rehydration ratio, and mold and yeast count of sun-dried tomatoes

	Concentration of sodium metabisulfite				
	0%	4%	6%	8%	Overall *F* test (*P* value)
Final moisture content (% wet weight)[a,b]	13.1a	14.0a	14.0a	14.0a	0.0001
Sulfur dioxide (ppm dry weight)	21a	1044c	3340b	5579a	0.0001
Color (hue°)	36.9a	33.6b	32.9bc	32.2c	0.0001
Rehydration ratio	3.10b	3.24ab	3.26ab	3.34a	0.0098
Mold log(CFU/g)[c]	1.0	1.4	1.5	1.6	0.1603
Yeast log(CFU/g)[c]	4.9a	1.8b	1.4b	1.9b	0.0018

[a]All means are based on triplicate values.
[b]Means within a row with different letters are significantly different ($P < 0.05$).
[c]Statistical analysis was on log transformed data. CFU = colony-forming units.

sodium metabisulfite increases, the color values (hue°) decrease (Figure 3) inferring a redder and more desirable color. It is generally accepted that sulfur dioxide prevents color degradation during drying. Sun-dried tomatoes that had been dipped in an 8% sodium metabisulfite solution had the highest sulfur dioxide content, and thus the best red color (32.2 hue°). This value was significantly different from the other treatments, except the 6% metabisulfite, which had a hue angle of 32.9.

There was a increase in rehydration ratio (Table 4; Figure 3) and a significant difference between the control and 8% sodium metabisulfite treatment ($P < 0.05$) as the concentration of dipping solution increased. Sun-dried tomatoes that were dipped in 8% sodium metabisulfite had the best rehydration ratio (3.34), whereas the control tomatoes had the worst (3.10). These results are consistent with studies reported by Tripathi and others (1989) and Olorunda and others (1990), which have shown that the use of metabisulfite solutions as a pretreatment before drying tomatoes improves their rehydration.

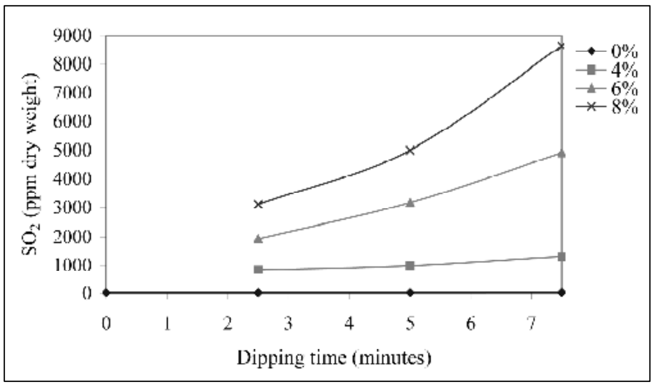

Figure 2—Effect of dipping time and concentration of the sodium metabisulfite dip solution on sulfur dioxide content (ppm dry weight) of sun-dried tomatoes

Significant differences in yeast count were observed (Table 4) between the control and pretreated tomatoes ($P < 0.05$). Dipping in sodium metabisulfite decreased yeast growth in sun-dried tomatoes (Figure 3). Due to a high initial yeast count of 4.9 log CFU/g, untreated sun-dried tomatoes developed an undesirable fermented off-odor and physical signs of spoilage. Tomatoes treated with sodium metabisulfite did not show signs of spoilage or off-odors and had lower yeast counts than those not treated or dipped in salt.

The recommended combination of sodium metabisulfite concentrations and dipping time to improve color and rehydration ratio and to control yeast growth are 6% or 8% sodium metabisulfite for 5 min (Figure 3). Sun-dried tomatoes produced under these combinations had 3168 ppm of sulfur dioxide when dipped in 6% sodium metabisulfite and 5000 ppm of sulfur dioxide when dipped in 8%. Although the limits of sulfite are generally established according to the purchasing company's specifications, Davis and others (1973) recommend that dried fruit producers should aim for an initial sulfur dioxide content of 3000 mg/kg to ensure continuity of supply of acceptable dried fruits from 1 season to the next.

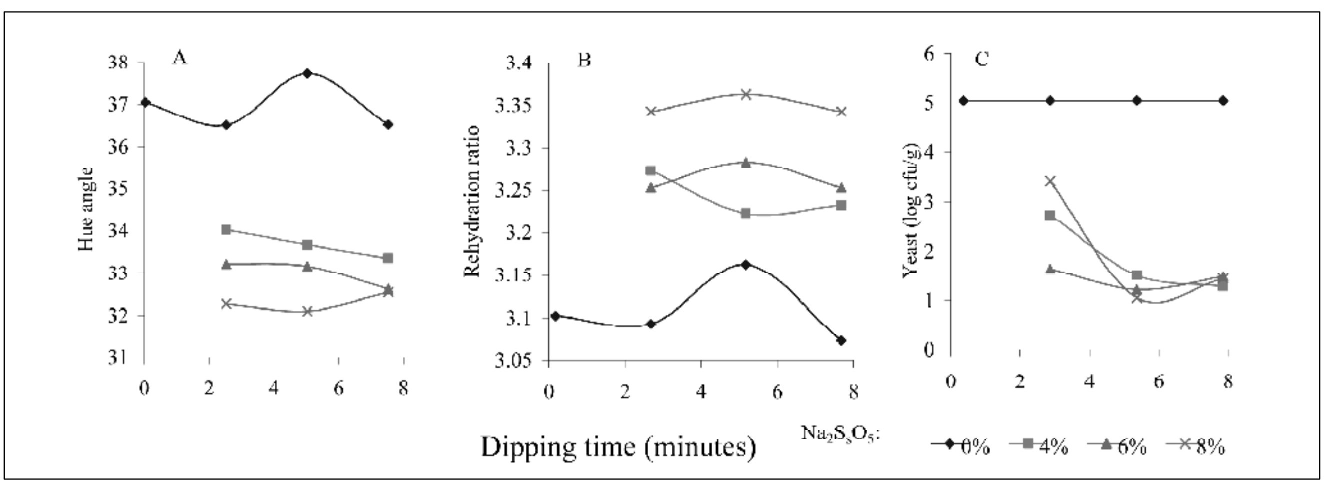

Figure 3—Effect of dipping time and sodium metabisulfite concentration on (a) hue angle, (b) rehydration ratio, and (c) yeast count (log colony-forming units [CFU]/g) of sun-dried tomatoes

Table 5—Quality parameters of sun-dried tomatoes before and after 3 mo storage at 25 °C and 30% to 34% relative humidity

Pretreatment[a]	Storage period (mo)	Moisture[b] (%wet basis)	Color (hue°)	Rehydration ratio	Mold (CFU/g)	Yeast (CFU/g)	SO_2 (ppm dry weight)	Salt (% dry weight)
Control	0	13.1	36.9	3.1	<10	114333	—	0.6
	3	14	42.0*	2.94*	<10	147**		0.6
SO_2	0	16	32.2	3.04	37	<10	2461	—
	3	14	37.7*	2.99	30	<10	1136*	
Steam + SO_2	0	11.4	32.4	3.05	17	<10	1587	—
	3	12	36.0*	2.96	20	<10	907*	
Boiling water + SO_2	0	9.1	32.7	3.04	27	<10	1423	—
	3	10.8	36.0*	2.71	<10	<10	773*	
Boiling brine + SO_2	0	9	31.9	2.84	13	<10	1555	6.7
	3	12.4*	36.3*	2.79	<10	<10	697*	5.2*
10% NaCl	0	17	35.7	2.6	<10	8450	—	10.9
	3	17.5	41.6*	2.55	13	<10*		9.2*
15% NaCl	0	16.3	36.5	2.53	73	93	—	12.1
	3	16	41.3*	2.48*	13	<10		9.9*
6% $Na_2S_2O_5$	0	14.5	33.1	3.28	47	20	3169	—
	3	14	36.6	3.26	13	<10	930*	
8% $Na_2S_2O_5$	0	13	32	3.36	30	<10	4999	—
	3	13	36.8	3.34	20	<10	1725*	

[a]Pretreatments before sun drying: Control = no pretreatment; SO_2 = direct gas sulfuring for 12 h; Steam + SO_2 = steam blanched for 60 s and direct gas sulfuring for 12 h; Boiling water + SO_2 = blanched in boiling water for 40 s and direct gas sulfuring for 12 h; Boiling brine + SO_2 = boiled brine blanched for 40 s in 7.5 % salt and direct gas sulfuring for 12 h; 10% NaCl = dipped in 10% salt for 5 min; 15% NaCl = dipped in 15% salt for 5 min; 6% $Na_2S_2O_5$ = dipped in 6% sodium metabisulfite for 5 min; 8% $Na_2S_2O_5$ = dipped in 8% sodium metabisulfite for 5 min. CFU = colony-forming units.
[b]Means for all analytical measurements are based on triplicate values. Significant differences within a quality parameter for a treatment are denoted by an asterisk (** = P < 0.01; N = 3); (* = P < 0.05; N = 3).

Change of quality parameters during storage

Babalyk and others (1997) reported that optimal storage conditions for sun-dried tomatoes are at low temperatures (5 °C) to minimize sulfur dioxide loss and thus decrease browning. In the present work, the storage temperature of 25 °C was selected so results would apply to sun-dried tomatoes not stored or transported in low temperature facilities. Therefore, changes in some quality parameters would be expected to happen faster than with cold temperature storage. While many processors do store sun-dried tomatoes at refrigeration or freezing temperatures, others do not. The use of 25 °C storage in the present study may be viewed as an accelerated temperature storage condition. As explained in the methods, only 9 pretreatments were selected for analysis after 3 mo of storage. Table 5 shows the changes in quality parameters after storing sun-dried tomatoes packed in sealed polyethylene bags for 3 mo at 25 °C and 30% to 34% relative humidity. There were no significant changes (P> 0.05) in final moisture content after 3 mo of storing sun-dried tomatoes, except with the boiling brine + SO_2 pretreatment.

Significant losses in sulfur dioxide content (P < 0.05) were observed in all sulfured sun-dried tomatoes after 3 mo of storage. Sun-dried tomatoes containing the highest amount of sulfur dioxide (6% $Na_2S_2O_5$ and 8% $Na_2S_2O_5$) lost up to about 70% of their initial sulfur dioxide content, whereas those initially containing lower amounts of sulfur dioxide (SO_2, steam + SO_2, boiling water + SO_2, and boiling brine + SO_2) lost up to about 55%. Similar results were obtained by Babalyk and others (1997), who showed that the sulfur dioxide degradation rate for sun-dried tomatoes containing a high amount of sulfur dioxide (approximately 4000 ppm) and stored at 30 °C was higher than that for those containing lower amounts (approximately 1000 ppm).

After 3 mo of storage, the sulfur dioxide was lost to almost a constant level of 700 to 1136 ppm with all pretreatments except the highest initial SO_2 (8% $Na_2S_2O_5$) in which the final sulfur dioxide content after storage was 1725 ppm (Table 5). The loss in sulfur dioxide during storage subsequently caused changes in the color of the stored sun-dried tomatoes. Hue angles increased in all pretreatments after 3 mo of storage; however, significant differences (P< 0.05) were observed only in the control, SO_2, steam + SO_2, boiling water + SO_2, boiling brine + SO_2, and 10% and 15% NaCl pretreatments. It was evident that sulfur-treated sun-dried tomatoes retained better red color than unsulfured ones. Sulfites may block the formation of brown pigments in the Maillard reaction pathway (Taylor and others 1986; Sulaeman and others 2001). After 3 mo of storage, sodium metabisulfite–treated sun-dried tomatoes (6% and 8% $Na_2S_2O_5$) had lower hue angles (36.6 and 36.8 hue°, respectively) than gas-sulfured sun-dried tomatoes (SO_2 pretreatment 37.7 hue°) and thus more intense red color.

Although tomatoes were blanched either in steam, water, or brine, gas-sulfured (steam + SO_2, boiling water + SO_2, and boiling brine + SO_2) and sun-dried had the lowest sulfur dioxide content after 3 mo of storage (Table 5), their hue angles were the lowest compared with all other pretreatments (36.0, 36.0 and 36.3 hue°, respectively). This could be due to blanching slices immediately after cutting, thereby inactivating polyphenoloxidase and minimizing enzymatic browning. Sanguansri and others (1995) reported that the color of sun-dried tomatoes was significantly improved by blanching in boiling water before air-drying. Compared with unblanched and sulfur gassed tomatoes, those that were blanched before sulfuring did not show significant differences in color immediately after sun-drying; rather, the blanched tomatoes only appeared more intensely red after 3 mo OF storage.

Control sun-dried tomatoes had the highest hue angles both before (36.9 hue°) and after storage (42.0 hue°) exhibiting a dark brown color (Table 5). It has been reported that salt reduces enzymatic browning and discoloration (Brenndorfer and others 1987). However, in this study, salt-dipped sun-dried tomatoes (10% NaCl and 15% NaCl) had high hue angles both before and after storage and could not be distinguished visually from the control because both appeared to have a dark brown color.

Significant decreases in the rehydration ratio of sun-dried tomatoes before and after storage (P< 0.05) were only observed between the control and the 15% NaCl pretreatment, but in general this quality parameter decreased with all pretreatments (Table 5). The highest rehydration ratios (3.26 and 3.34) obtained after storage were from the 6% $Na_2S_2O_5$ and 8% $Na_2S_2O_5$ pretreatments, respectively, followed by the SO_2 pretreatment with a rehydration ratio of 2.99. Therefore, the sodium metabisulfite-treated sun-dried tomatoes were the best in terms of rehydration properties.

All mold counts were initially under allowable limits (10^4/g), and no significant changes were observed after storing sun-dried tomatoes for 3 mo. However, the control and tomatoes treated with 10% NaCl showed significant decreases ($P < 0.01$) in yeast count after storage (Table 5), suggesting that viable yeast did not survive storage conditions.

Significant losses in salt content were observed with the boiling brine + SO_2, 10% NaCl, and 15% NaCl pretreatments (Table 5). Some or all of these losses could be a consequence of the antioxidant effect of salt; when free of heavy metals, salt may inhibit oxidation (Brenndorfer and others 1987). Other possible reasons for salt losses may have resulted from handling and packaging sun-dried tomatoes after storage.

Conclusions

The use of sulfur dioxide gas before drying improves the quality of sun-dried tomatoes. The use of either salt or sodium metabisulfite dips inhibited yeast growth, but the quality of sodium metabisulfite–dipped sun-dried tomatoes was superior. Salt-dipped sun-dried tomatoes are a good option for consumers wishing to avoid the use of sulfur dioxide as a preservative; however, the color of these products is typically darker. The use of sodium metabisulfite dips may offer a safer, more convenient, and more controllable method for producing high-quality sun-dried tomatoes.

After 3 mo storage, significant losses in sulfur dioxide content were observed in all sulfured sun-dried tomatoes. Sun-dried tomatoes containing higher initial amounts of sulfur dioxide lost more after storage than those containing lower amounts. Tomatoes treated with a sodium metabisufilte dip had a redder color (lower hue angles) and better rehydration than those sulfured with gas.

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