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Change in color and other fruit quality characteristics of tomato cultivars after hot-air drying at low final-moisture content

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Abstract
The present study aimed to evaluate the drying quality of three tomato cultivars (Amoroso, Berlinto and Messina) at low final-moisture content. Tomatoes were cut into slices and hot-air-dried from 92% (wet basis) to 12% final moisture content at 55°C, 65°C and 75°C at 1.5 m/sec air flow. Color, total soluble solids (TSS), titratable acidity (TA) and ascorbic acid (AA) content were measured in both fresh and dried tomatoes. Brightness of the dried tomato slices was significantly decreased, while intensity of the red and yellow colors and brightness of the red color (a^*/b^*) increased. Low overall color change (ΔE) was obtained at the lowest drying temperature (55°C). Messina and Amoroso showed a higher a^* value and lower ΔE, respectively. The TSS content was increased, while the TA and AA contents were decreased through drying. This study shows that it is possible to hot-air dry tomato slices to a final moisture content of 12% maintaining quality that is comparable with studies where the final-moisture content was higher (15% or more).

Keywords: *Tomato, hot-air drying, color, total soluble solids, titratable acid, ascorbic acid*

Introduction

Tomatoes, *Lycopersicon esculentum M.*, are used both in fresh and processing markets. Tomato can be preserved and processed in various ways: canned, dried or made into juice and sauces. Hot-air drying, sun-drying, solar-tunnel drying, microwave drying and freeze-drying are amongst the most commonly used methods to dry and preserve tomatoes. Sun-drying is a common practice to preserve and store fruits and vegetables in the tropics and subtropics, especially at household level, while hot-air drying is more common in other parts of the world as an industrial drying method (Ratti and Mujumdar 2005; Chang et al. 2006; Latapi and Barrett 2006a, 2006b; Heredia et al. 2007).

Drying tomato at high temperatures can cause damage in certain quality parameters such as color and ascorbic acid (Zanoni et al. 1999; Kerkhofs et al.

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2005; Chang et al. 2006; Toor and Savage 2006). The color change in food material during thermal processing is caused by the reactions taking place inside it, such as pigment degradation (especially carotenoids and chlorophyll), and browning reactions such as Maillard condensation of hexoses and amino components and oxidation of ascorbic acid (Barreiro et al. 1997; Lozano and Ibarz 1997; Lee and Coates 1999). Therefore, the final values of color parameters can be used as quality indicators to evaluate deterioration due to thermal processing (Shin and Bhownik 1995). The ascorbic acid (AA) content varies among cultivars of tomato, and decreases significantly following air-drying (Kerkhofs et al. 2005; Chang et al. 2006). On the other hand, drying enhances total antioxidant activities by increasing total flavonoids, total phenolics and lycopene contents (Dewanto et al. 2002; Chang et al. 2006).

Total soluble solids (TSS), titratable acidity (TA) and aroma volatile composition are all associated with flavor and are commonly measured as part of fruit quality assessment. Sweetness and sourness have a high correlation with the contents of TSS and pH. Tomato flavor is the result of complex interactions between many compounds. However, empirical tests have shown that tomato flavor is strongly correlated with TSS content and TA, as well as their interaction (Stevens et al. 1977). Therefore, understanding those factors affecting TSS and TA contents is important for quality evaluation. Previous studies have investigated the non-thermal factors that affect TA and TSS contents of fresh tomato (Anza et al. 2006; Polenta et al. 2006; Thybo et al. 2006) and the effect of processing temperatures on TSS and TA of tomato paste (Sherkat and Luh 1976; Gould 1978; Anese et al. 2003). No literature was found on the effect of hot-air drying on TSS content of tomato slices. Recently, Khazaei et al. (2008) reported that drying of tomato slices caused an increase in soluble solids and acidity, while pH and AA decreased.

The type and extent of the effects of drying tomato on quality characteristics are dependent on the methods of drying (heat source, amount and duration of temperature and final moisture content of the product), the pre-treatment procedures, and the cultivars (Zanoni et al. 1999; Kerkhofs et al. 2005; Chang et al. 2006; Latapi and Barrett 2006a, 2006b; Heredia et al. 2007). Therefore, the aim of the present study was to evaluate the change in color, TSS, TA and AA contents of commercially available tomato cultivars in Austria after hot-air drying at three different temperature levels to a relatively low final moisture content of 12%.

Materials and methods

Fruit sampling

Three commercially grown tomatoes cultivars, namely Amoroso, Berlinto and Messina, were grown in a plastic tunnel from March to September 2008 in Vienna, Austria. Proper plant management activities were carried out in order to secure a good harvest. Fully matured fruits were harvested from the central stem and were sorted visually within cultivars for color, size uniformity and absence mechanical damage. Thus, uniform, clean and healthy fruits of each cultivar were used for the experiment.

Color measurements

Fruit color was determined by direct reading using a chroma-meter (MINOLTA model CR-200; Minolta Camera Co., Ltd., Osaka, Japan) to obtain the color values: $L^\star$ (brightness/darkness), $a^\star$ (redness/greenness) and $b^\star$ (yellowness/blueness). The measurements were taken from randomly selected fresh fruits at three different parts (around halfway from the blossom end) of a fruit and averaged. It should be noted that these same fruit parts were dried and subject to color measurement after drying. The total color change (ΔE) was then calculated using the following equation

$$\Delta E = [(L_0{*} - L{*})^2 + (a_0{*} - a{*})^2 + (b_0{*} - b{*})^2]^{1/2} \tag{1}$$

where $L_0^\star$, $a_0^\star$ and $b_0^\star$ represent the value before drying, and $L^\star$, $a^\star$ and $b^\star$ represent the values after drying at each temperature level.

Initial moisture content determination

The initial moisture content (wet basis) was determined using an oven drier (model EHRET; EHRET GmbH, Emmendingen, Germany) at 105°C until no further change in dry weight was obtained, according to the AOAC procedure (AOAC 2000). Moisture content was measured in triplicate and the average value was taken for calculation. The remaining fruits for each cultivar were subsampled into two, for fresh fruit analysis (without drying—as control) and for drying.

Extraction and analysis from fresh fruits

Tomato fruit juice for each cultivar was prepared using a juice extractor (model BRAUN-MP80; Braun GmbH, Kronberg, Germany). Juiced samples were stored in a deep freezer at −20°C until the analysis. Frozen juiced samples (three samples from each cultivar) were thawed overnight at 4°C and filtered using filter paper to obtain pure supernatant for AA, TSS and TA measurements. AA was extracted using 1% oxalic acid and measured using reflectoquant ascorbic acid test strips in a RQflex reflectometer as described by Neocleous and Vasilakakis (2008) and the value expressed in milligrams per liter. The TSS content was measured using a digital hand refractometer (model PT-32; ATAGO Co., Ltd., Tokyo, Japan) and expressed in °Brix at 20°C (Khazaei et al. 2008). Ten microliters of supernatant was diluted in 20 ml distilled water to measure TA using a TitroLine alpha plus (model SCHOTT TA20 plus; SCHOOT-GERÄTE GmbH, Mainz, Germany). The sample was titrated to pH 8.1 using 0.1 mol/l NaOH (Thybo et al. 2006) and expressed in milliliters per liter.

Drying process

Hot-air drying of tomato was carried out in the Department of Sustainable Agricultural Systems (BOKU University) using computer-monitored hot-air drying cabinets. Tomatoes were cut into approximately 5 mm thick slices and placed on wire mesh racks in two rows of four slices in three cabinets at temperatures of 55°C, 65°C and 75°C at 1.5 ± 0.04 m/sec air flow. All the three cultivars were subjected to one of the temperatures in different cabinets at a time. Fruit slices were dried from a 92% moisture content (wet basis) to a final moisture content of about 12% by measuring the weight loss every 30 min at the beginning and more frequently towards the end of the drying period. The total drying time was recorded. The drying process was replicated three times. The dried fruit slices were placed in a desiccator for about 15 min for cooling. After measuring the color values, the dried fruit slices were stored inside air-tight plastic bags and wrapped with aluminum foil and kept in a deep freezer until sample extraction commenced.

Extraction and analysis from dried fruits

A dried and frozen 5 g sample (pooled randomly from four dried slices) from each cultivar was further frozen using liquid nitrogen so that it could be ground finely to powder in a mortar. The powder was diluted 10 times with distilled water and centrifuged for 10 min at 2,500 rpm (Centrifuge model Heraeus Christ LABOFUGE III; LABCON GmbH, Heppenheim, Germany). The same procedures used in the fresh fruit analysis were followed to determine AA, TSS and TA values in the supernatant.

Data analysis

All measurements were replicated three times. The data obtained from different measurements and chemical analyses were analyzed using SAS version 9.1.2 (SAS Institute Inc., Cary, NC, USA). The SAS general linear model procedure was used for two-way analysis of variance on each parameter. Probabilities for all pairwise differences (pairwise comparisons) were computed. Values after the '±' symbol indicate the standard error.

Result and discussion

Color

The results show that all color parameters ($L^\star$, $a^\star$ and $b^\star$) changed significantly after hot-air drying. There was no significant interaction between cultivar and temperature for any of the color parameters. The brightness ($L^\star$ value) of tomato slices was significantly decreased ($P<0.0001$) on average by 13.5% after hot-air drying in all cultivars (Table I). This is in agreement with a previous study by Toor and Savage (2006), who reported a more than 30% increase in darkness at 42°C for 18 h (a relatively lower temperature and longer drying period than was used in the present study). The change in color can be either due to pigment degradation or browning reaction or both during dehydration (Lopez et al. 1997; Shi et al. 1999). Brightness was significantly lower at 55°C compared with 65°C and 75°C. This could be related to the drying time to which each sample was subjected. The samples at 55°C were dried for a significantly ($P=0.007$) longer time (244 ± 5.9 min) than those at 65°C and 75°C (185 ± 7.9 min and 159 ± 5.8 min, respectively). Lower temperature with longer drying periods may cause more damage than higher temperatures for shorter drying time (Goula and Adamopoulos 2006; Khazaei et al. 2008). There was no significant variation in brightness among cultivars.

The values of $a^\star$ and $b^\star$ increased significantly after drying ($P<0.0001$). Fruit slices increased in $a^\star$ and $b^\star$ on average by 68% and 49%, respectively. There was no significant difference among the three levels of drying temperature for $a^\star$ but there was a significant difference among cultivars. Messina has significantly higher $a^\star$ value than the other two cultivars ($P=0.0164$). The value of $b^\star$ was significantly ($P<0.0001$) higher at 65°C and 75°C than 55°C. Previous studies have also reported the decrease in brightness of red color ($a^\star/b^\star$ value) in tomato after air-drying (Shi et al. 1999; Kerkhofs et al. 2005). However, in the present study $a^\star/b^\star$ was increased significantly

Table I. Two-way analysis of variance for color parameters (least square means ± standard error, $n = 63$) of three tomato cultivars.

Cultivar/temperature	$L^\star$	$a^\star$	$b^\star$	$a^\star/b^\star$
Amoroso				
Fresh	38.3 ± 0.18	17.7 ± 0.43	18.2 ± 0.37	0.97 ± 0.01
55°C	32.5 ± 0.61	26.2 ± 0.61	21.9 ± 0.31	1.19 ± 0.02
65°C	34.8 ± 0.22	28.3 ± 0.39	28.2 ± 0.39	1.01 ± 0.02
75°C	33.9 ± 0.23	29.3 ± 0.51	27.2 ± 0.39	1.09 ± 0.02
Berlinto				
Fresh	38.5 ± 0.15	15.8 ± 0.30	16.6 ± 0.32	0.95 ± 0.09
55°C	30.9 ± 0.31	27.5 ± 0.20	23.9 ± 0.13	1.15 ± 0.01
65°C	32.9 ± 0.23	27.2 ± 0.19	26.0 ± 0.15	1.05 ± 0.01
75°C	34.6 ± 0.20	28.4 ± 0.22	25.9 ± 0.35	1.10 ± 0.01
Messina				
Fresh	39.2 ± 0.10	18.1 ± 0.53	17.6 ± 0.46	1.03 ± 0.01
55°C	31.5 ± 0.45	31.3 ± 0.36	24.5 ± 0.27	1.28 ± 0.01
65°C	34.5 ± 0.22	29.8 ± 0.33	27.8 ± 0.48	1.09 ± 0.02
75°C	35.6 ± 0.13	31.3 ± 0.53	28.0 ± 0.20	1.12 ± 0.01
Source of variation				
Cultivar, 2 degrees of freedom	ns	**	ns	ns
Temperature, 3 degrees of freedom	***	***	***	***
Cultivar x temperature, 6 degrees of freedom	ns	ns	ns	ns

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$; ns, not significant.

($P < 0.0001$) after drying because of the increased $a^\star$ value. This is in agreement with the report by Toor and Savage (2006) for tomatoes semi-dried at a lower temperature of 42°C. Similarly, in the present study the highest $a^\star/b^\star$ value was obtained at lowest temperature (55°C) in all cultivars. No significant variation was observed among cultivars in the $b^\star$ and $a^\star/b^\star$ values.

The overall color change (ΔE) was significantly higher ($P = 0.0261$) at higher temperatures (65°C and 75°C) than at lower temperature (55°C) (Figure 1). Similarly, Barreiro et al. (1997) and Shi et al. (1999) also reported the increase in ΔE as temperature increased. There was a significant ($P = 0.0396$) difference among cultivars in the overall color change. The overall color change in Amoroso (14.6 ± 0.62) was significantly lower than that in Berlinto and Messina (16.6 ± 0.67and 16.9 ± 0.67, respectively).

Total soluble solids, titratable acidity and ascorbic acid

Significant changes in TSS, TA and AA after hot-air drying were obtained due to variation in the level of temperature, but there was no significant difference among cultivars and no interaction between cultivar and temperature. The decrease in moisture content in the fruits is usually accompanied by an increased percentage of TSS, since TSS is the major component of dry matter (Malundo et al. 1995). Thus, the value of TSS significantly ($P < 0.0001$) increased after drying (Table II). This increase was up to five-fold, which is much higher than a maximum 22% increase at

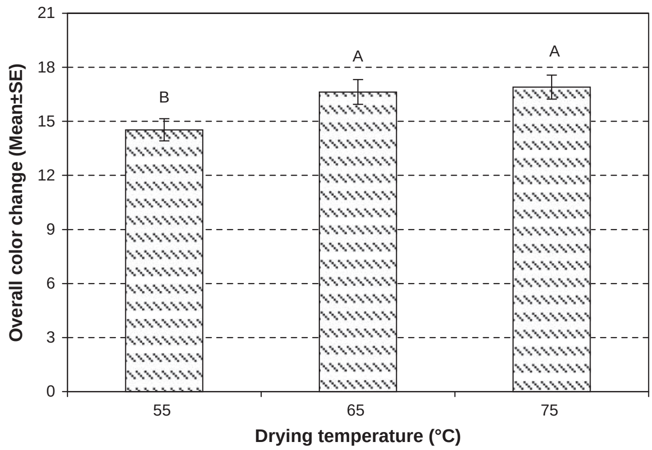

Figure 1. Overall color change (ΔE) of three tomato cultivars following hot-air drying at three levels of temperature ($n = 45$). Bars with the same letter are not significantly different ($\alpha = 0.05$).

60°C reported by Khazaei et al. (2008). Although there was no significant difference in the TSS value between the three levels of drying temperature, the value increased with increasing temperature and then decreased at 75°C in Amoros and Berlinto. Similarly, Khazaei et al. (2008) reported that the TSS value increased with increasing drying-air temperature but decreased at 80°C and above.

The TA value significantly decreased after drying ($P < 0.0001$), up to 45%. This result contrasts with previous studies that reported an increase in TA following drying (Toor and Savage 2006; Khazaei et al. 2008). However, Piga et al. (2004) reported a decrease in TA after hot-air drying of figs (*Ficus carica L.*). The AA content of fresh tomato also significantly decreased ($P < 0.0001$), to about one-half its original content, after drying. This result is in agreement with several studies (Kerkhofs et al. 2005; Chang et al. 2006; Toor and Savage 2006; Khazaei et al. 2008) that reported degradation of AA at high temperatures. Amoroso had lower AA content compared with the other two cultivars both in fresh and dried forms, but there is no significant difference in AA change among cultivars after drying.

Conclusion

The present study shows that it is possible to hot-air-dry tomato slices to a final moisture content as low as 12% maintaining quality levels that are comparable with those reported in other studies where final moisture contents were 15% and above (Kerkhofs et al. 2005; Toor and Savage 2006; Khazaei et al. 2008). This additional reduction in moisture content is important as it means that the weight and volume (and hence the cost) to store or transport dried tomato can be reduced. A 10°C decrease in hot-air drying temperature brings about a 15–16% increase in drying period. Hence, using higher temperature for shorter drying periods may help to decrease the darkness of dried tomato slices. However, the overall color quality (ΔE) that influences consumer acceptability becomes worse as temperature increase. Although there is no difference in measured parameters among cultivars after drying, Amoroso appears to be the most suitable cultivar for hot-air drying for its potential to retain its overall color. The TSS, TA and AA contents of tomato slices are highly

Table II. Two-way analysis of variance for TSS, TA and AA (least square means ± standard error, $n = 35$) of three tomato cultivars.

Cultivar/temperature	TSS	TA	AA
Amoroso			
Fresh	6.4 ± 0.06	4.66 ± 0.03	292 ± 7.52
55°C	33 ± 0.33	2.56 ± 0.04	129 ± 3.02
65°C	35 ± 0.00	3.50 ± 0.09	133 ± 4.63
75°C	31 ± 0.62	2.53 ± 0.05	122 ± 2.09
Berlinto			
Fresh	6.2 ± 0.04	4.58 ± 0.06	320 ± 6.80
55°C	33 ± 0.65	2.50 ± 0.04	155 ± 4.98
65°C	33 ± 0.76	2.71 ± 0.01	146 ± 2.78
75°C	30 ± 0.29	2.55 ± 0.04	116 ± 2.25
Messina			
Fresh	6.1 ± 0.07	4.70 ± 0.07	296 ± 2.83
55°C	32 ± 0.44	2.77 ± 0.07	159 ± 4.77
65°C	31 ± 0.22	2.76 ± 0.06	147 ± 2.96
75°C	32 ± 0.45	2.61 ± 0.01	152 ± 1.44
Source of variation			
Cultivar, 2 degrees of freedom	ns	ns	ns
Temperature, 3 degrees of freedom	***	***	***
Cultivar x temperature, 6 degrees of freedom	ns	ns	ns

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$; ns, not significant.

affected by hot-air drying. High TSS with reasonable amount of TA may contribute to the sweetness and flavor of dried product. AA degradation is one of the main limiting factors for drying tomatoes. As reviewed by Sablani (2006), pre-treatments are required to reduce AA loss. In this study, there was no significant difference in any of the quality parameters for tomato dried at 65°C and 75°C. As drying at 75°C reduces the drying time, it is preferable to use this temperature. Further studies need to be carried out to investigate the effect of pre-treatments on the quality of dried products at 12% final moisture content.

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