Physicochemical Properties and Shelf-Life of Regular-fat Sausages with various Levels of Grape Tomato Powder Prepared by Different Drying Methods

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Abstract

This study was aimed to investigate the physicochemical properties, texture, and antioxidant and antimicrobial activities of regular-fat sausages mixed with 0.25 and 0.5% of oven-dried and freeze-dried grape tomato powder (GTP, 150-μm) during storage at 4°C. Regular-fat sausages were made by six treatments that included: control (CTL), REF (sausages with 0.1% ascorbic acid alone), F1GTPSs (F1) and F2GTPSs (F2) (sausages with 0.25 and 0.5% freeze-dried grape tomato powder), and O1GTPSs (O1) and O2GTPSs (O2) (sausages with 0.25 and 0.5% grape tomato powder oven-dried at 100 °C). Sausages with added oven-dried grape tomato powders (OGTPs) showed decreased pH, lightness (L*), total plate count (TPC), and thiobarbituric acid-reactive substances (TBARS) compared to the sausages mixed with freeze-dried grape tomato powder (FGTPSs), but also had the highest redness (a*) and yellowness (b*) values among the treatments. With increasing levels of GTP, the hardness and chewiness of the sausages gradually decreased and these were decreased more in the FGTPSs (F) than in the OGTPSs (O). Compared to the FGTPSs, OGTPSs had higher antioxidant and antimicrobial activities, which extend the shelf-life of meat products. Application of OGTP to regular-fat sausages resulted in higher lipid antioxidant, antimicrobial activities, improving physicochemical properties and extended the shelf-life.

Keywords: grape tomato powder, physicochemical and textural properties, antioxidant and antimicrobial activities, regular-fat sausages

Introduction

Fresh and processed tomatoes are rich sources of bioactive compounds, including

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carotenes (lycopene, β-carotene), ascorbic acid, flavonoids, flavone, tocopherol, and phenolic compounds, and tomatoes are the most consumed vegetable in the world (Frusciante et al., 2007). Studies have reported that increased consumption of tomatoes prevents the incidence of chronic degenerative diseases, such as certain types of cancer and cardiovascular diseases (Giovannucci, 1999; Omoni and Aluko, 2005). Among the bioactive compounds in tomato, lycopene is the major carotenoid compound, which gives the red color to the fruit and has been shown to exert strong antioxidant activity and high physical quenching rate constant with singlet oxygen (Mascio et al., 1989; Agarwal and Rao, 2000).

Grape tomatoes are convenient to eat, which taste sweet and flavorful, and could be regarded as a good source of lycopene and vitamins (Simonne et al., 2008). However, grape tomatoes have a high water loss because of their small size and they contain high concentration of sugar and acid, which is major contribute to the acceptable flavor and consumption (Cantwell et al., 2009). Taveira et al. (2010) studied on antimicrobial agent of *Lycopersicon esculentum* Seeds, and they reported that extracts of tomato seeds displayed antimicrobial activities about gram-positive bacteria and fungi.

There were not many papers to report the differences between big tomato and grape tomato. However, many differences in chemical composition have been reported between traditional varieties (big tomatoes) and the new small-sized varieties (cherry tomatoes), which were characterized by higher dry matter and a soluble solid fraction, essentially due to the higher levels of sugars and organic acids (Muratore et al., 2005; Picha, 1986). Muratore et al. (2005) evaluated the chemical composition about various small-sized tomatoes, and they found that the level of polyphenols compounds in small-sized tomatoes

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was higher than those in normal-sized ones due to the greater skin/volume ratio (Muratore et al., 2005). They also reported that grape tomatoes had higher phenolic substances and lycopene contents than those of cherry tomatoes and simultaneously, sugars and health-promoting components (ascorbic acid, phenolic compounds and carotenoids) of grape tomatoes are displayed with high amounts (Muratore et al., 2005). Grape tomatoes, which are about half size of cherry tomatoes, are meatier, thicker skin, less watery and less sweetness than cherry tomatoes (Christine, 2014).

There were many processes for the manufacture of food powders. Drying is the typical process for fruits and vegetables, since drying fruits and vegetables lead to water removal, which retards the growth of spoilage microorganisms, as well as the occurrence of enzymatic or non-enzymatic browning reactions in the material matrix, preserving the structure, sensory characteristics and nutritional value of the starting material for long periods (Aguilera, 2003; Zhang et al., 2006; Argyropoulos et al., 2011). However, drying has adverse effects on the final product quality, such as tissue browning and remarkable changes in the flavor profile (Lewicki et al., 2002). Among the drying methods, freeze-drying removes water from a frozen material mainly by sublimation to preserve the product quality (Ratti, 2001). However, this process is slow and requires expensive equipment, such as freeze-dryers (Utpal et al., 2014). Thus, it is rarely used for the preservation of cultivated grape tomatoes and is used for precious wild edible species and medicinal species (Bhatta et al., 2020). Oven-drying reduces the vitamin C content and increases the water-soluble, R-tocopherol, and Trolox analog antioxidant content (Lavelli et al., 1999). Phenolics in tomatoes remain stable under high temperature and contribute to the high level of antioxidant activity (Dewanto et al., 2002).

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The improvements in the antioxidant activity, resulting in the extended shelf-life of meat and meat products, were reported by Kim and Chin (2016). Presently, consumers have become more conscious of healthy foods with decreased fat, salt, and cholesterol content in meat and meat products, as well as vegetables and fruits rich in dietary fiber (Yang et al., 2007). Enhancements of meat and meat products with vegetables, fruits, and their fibers could reduce production costs and improve the technological and nutritional quality of the products (Serdaroğlu et al., 2018). Grape tomato is one of the most important types of tomatoes for fresh consumption and its consumption grows every year due to the flavor (perfect sugar to acid balance for a rich), sweetness, hearty skin, high yield and potential health benefits (Coker et al., 2018). In addition, grape tomatoes are different from traditional variety. Tomatoes dried at high temperatures displayed decreases in lightness and increased redness and yellowness because of a series of pigment degradation reactions (Ashebir et al., 2009). Simultaneously, antioxidant activities were reportedly increased because the drying technique increased the percentage of total phenolic compounds, total flavonoids, and lycopene content (Dewanto et al., 2002). Therefore, the objective of this study was to investigate the physicochemical properties, as well as the antioxidant and antimicrobial activities of regular-fat sausages to which grape tomato powder prepared by different drying methods was added.

Materials and Methods

Grape tomato powder preparations

Grape tomatoes were purchased from the local market and washed, chopped, and homogenized before drying by a freeze-dryer (FT5505, Ilshin, Daejeon, Korea) at -50°C

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and 7 mm Torr vacuum and a hot, dry oven (LDO-250F, Labtech, Ltd., Jeonju, Korea) at 100°C (Kim and Chin, 2016), respectively. The time and yield of freeze-drying and oven-drying at 100°C were 72 h and 9 h, and 9.59% and 8.2%, respectively. Then, the powder was sieved by two particle sizes (≥ 300 μm, ≤ 150 μm) and stored at -70℃.

Preparation of cooked pork regular-fat sausages

Pork ham and back fat were purchased from the local market (Samho Co., Gwangju, South Korea). After 60% lean meat and 20% fat were ground by an M-12s grinder (Fujee Plant, Busan, Korea), they were mixed with non-meat ingredients (18% ice water, 1.3% salt, 0.4% sodium tripolyphosphate (STPP), 0.25% cured blend, 0.05% sodium erythorbate, 0.1% ascorbic acid, and different kinds of tomato powder) (Table 1). Then, approximately 40 g of the meat batter was stuffed into 50 mL of centrifuge tube and centrifuged at 3000 rpm for 2 min. The sausage mixtures were cooked in a water bath at 75ºC for 30 min. All samples were taken out from tubes, then vacuum-packaged by food sealed plastic bags and stored in a refrigerator (10 ± 1℃) for 28 days. The whole experiment was performed triplicates. The pork regular-fat sausages were manufactured with the addition of grape tomato powder except for control (without addition of powder) and REF (with addition of 0.1% ascorbic acid), according to the procedure of Lee and Chin (2009).

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pH, color value, and microbial count

The pH values of the samples were determined by a pH meter (Mettler-Toledo, Schwarzenbach, Switzerland). Each sample was cut into 6 pieces and lightness (L*), redness (a*) and yellowness (b*) were measured by a Minolta color reader (Model # CR-10, Minolta, Tokyo, Japan). For the microbial count, 10 g of sanitized and homogenized sample was mixed with 90 mL of sterilized water (0.9%) using a Stomacher Lab Blender and serial dilutions were made. Then, about 0.1 mL of the diluted sample was dispersed onto the surface of violet red bile (VRB) and total plate count (TPC) agar and incubated at 37ºC for 24 ~ 48 h.

Proximate composition

Moisture, crude fat, and crude protein (%) were conducted by following the AOAC guidelines (AOAC, 2005). The moisture contents were analyzed by dry-oven methods, whereby the materials were dried at 102ºC for 24 h. The crude fat content was determined by the Soxhlet extraction method and crude protein analysis was performed by the Kjeldahl protein determination.

Texture profile analyses (TPA)

A universal testing machine (Model 3344, Canton, MA, USA) was used to perform texture profile analysis according to a method described by Caine et al. (2003). The sausage samples (1.30 cm length and 1.30 cm diameter) were compressed with a 500-N load cell at an operational speed of 300 mm/min. The TPA values were expressed in terms of the hardness (gf), springiness (cm), gumminess (kg mm^{-1}), chewiness (kg mm^{-1}), and cohesiveness (ratio) of sausages. Ten samples were used for single texture profile analysis

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result of every sausage.

Expressible moisture (EM, %)

Accurately 1.5 g sample was weighed and wrapped using the 3 pieces of 1/4 filter paper and then centrifuged (3,000 rpm) for 15 min (VS-5000N, Vision Scientific Co. Ltd., Bucheon, Korea). Weights of both the filter paper and samples were measured again. The expressible moisture content of the samples was calculated as follows:

$$\text{Expressible moisture (\%)} = \Delta T * 100 / A$$

Where ΔT was the thimble weight difference before and after centrifugation. A was the initial weight of the sample.

Thiobarbituric acid-reactive substances (TBARS)

The oxidative rancidity was evaluated by TBARS (Shinnhuber and Yu, 1977). Each sausage sample mixed with 2.5% trichloroacetic acid (TCA, 3 mL) and 1% thiobarbituric acid (TBA, 17 mL) in a capped tube was accurately measured in grams. Then, the tubes were put into a boiling water bath for 30 min. The supernatant of each solution was mixed with 5 mL of chloroform and centrifuged at 2,000 × rpm for 5 min (VS-5000N, Vision Scientific Co. Ltd., Bucheon, Korea). Then, approximately 3 mL of petroleum was added to each supernatant and centrifuged. Finally, the clear solutions were analyzed by spectrophotometry (UV-1601, Shimadzu, Kyoto, Japan) at a wavelength of 532 nm.

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Statistical analysis

The sausage samples were analyzed at 0, 3, 7, 14, 21 and 28-day intervals during 10ºC chilled storage. Data were analyzed by two-way analysis of variance (ANOVA) using the SPSS 21.0 program for Windows. Duncan's multiple range test was used to determine significant differences at the 5% level.

Results and discussion

pH and color

Table 2 shows the pH and color values of the regular-fat sausages (RFS) with various amounts of GTP as affected by the different drying methods. Since the interaction between the treatments and storage time were not different ($p > 0.05$), the data were pooled by treatment within each storage time and storage time within the treatment. The addition of GTP tended to decrease the pH values and the addition of oven-dried powder reduced the pH more than freeze-dried GTP. The reduced pH of the RFSs with the addition of tomato powder might be due to the tomato powder itself (Condogan, 2002). The reason why the oven-dried powder reduced the pH more than the freeze-dried powder was that the Maillard reactions of the tomato powder during heating caused a browning reaction that decreased the pH (Baloch et al., 2000). Although the pH values of all treatments decreased on day 3, they increased thereafter toward to the end of storage. Condongan (2002) reported that the pH of tomato paste-added patties increased with storage time and the changes in pH might be due to microbial growth during the refrigerated storage. However, a decrease in the pH values during storage of frankfurters containing tomato paste was observed by Deda et al. (2007) who suggested that the decrease in pH was obviously due to an increase of lactic acid bacteria, which might grow during storage. However, no lactic acid bacteria might grow in this study due to little change in the pH values.

REF and CTL had higher lightness (L*) values and lower redness (a*) and yellowness (b*) values. The addition of GTP tended to decrease lightness, but increased redness and yellowness. In the comparison of two drying methods, O turned darker and yellower than the F. Condogan (2002) reported that lycopene, the red substance and the corresponding pigment antioxidant, was affected by increasing tomato paste levels from 5 to 15%, which could result in beef patties that were yellower, redder, and darker. Since the O already underwent a series of Maillard reactions due to drying at high temperatures, the addition of O to the sausages turned them to be yellow and darker color (Cosmai et al., 2013). Salem (2013) reported that pH was a very important factor that was related to the meat color, water-holding capacity, and texture of meat. He also reported that beef patties mixed with optimum amounts of tomato peel powder had better color values, more acceptable by consumers. During the storage time, the addition of GTP affected the pH and color of the sausages and the oven-dried powder affected these more than freeze-dried powder.

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Proximate composition

The proximate analyses of sausages with different amounts and drying methods of GTP are shown in Table 3. Processing and chemical changes are affected by the nutritional composition, such as protein, fat, and moisture during storage. During the storage period, neither moisture nor crude fat showed differences, but crude protein (%) was slightly increased compared to the control. Kim IS et al. (2011) did the study on low-fat sausages added with tomato powder, who found that protein content increased with the increased addition of tomato powder, simultaneously, fat and moisture were without any changes. They reported that increased protein contents were not only the tomato powder was added, but also because tomato has 10.3% of crude protein contents, which was agreement with our studies. Although the protein contents were different statistically, the proximate composition of the RFSs was not actually affected by GTP addition due to the small changes of the protein contents, regardless of the different drying methods and levels of GTP.

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Texture profile analyses (TPA)

Table 4 shows the textural properties of RFSs added with GTP and no interaction between treatments and storage time was found in the textural properties. The textural characteristics of cooked meat products are generally considered to be heat-induced changes in connective tissue, soluble proteins, and myofibrillar proteins (Zayas and Naewbanij, 1986). The hardness and chewiness values were decreased by the addition of GPT and the addition of FGTP into the sausages tended to decrease these characteristics more than OGTP. During the storage time, textural hardness and gumminess increased as the storage time increased. Na and Na (2012) reported that the addition of tomato powder decreased the texture of sausages. Thus, the addition of tomato peel and powder had different effects on texture due to their different functional characteristics. However, the opposite result was observed in a previous study from Salem (2013) who reported that hardness increased when tomato powder was added because of the increase in tomato peel fiber. The increase in hardness could be explained by the presence of insoluble acid detergent fiber, which is composed mainly of cellulose and lignin in tomato peel (Knoblich

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et al., 2005; Kim et al., 2011). Springiness was affected by the addition of F1GTP and O2GTP. However, no changes in springiness were found in O1 and F2. During the storage time, springiness decreased on 3 days of storage, increased on 21 days of storage and pleateau thereafter. Gumminess changed slightly, only increasing a little on day 3 days of storage and decreased with the addition of F2GTP. Chewiness decreased with the addition of GTP, but no differences were observed during storage time. Cohesiveness decreased with the addition of GTP, except for O2GTP, which was increased during storage. During the storage time, cohesiveness tended to decrease with increased storage time. Thus, except for a few cases, most textural characteristics were affected by the addition of GTP, especially FGTP rather than OGTP and storage time.

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TBARS

Since interaction between storage time and treatments was observed ($p < 0.05$), the data were separated by treatment within a storage time or storage time within a treatment (Table 5). Thiobarbituric acid-reactive substances (TBARS), which is used as an index for measuring the oxidative rancidity of meat and meat products, increased as storage time increased. The TBARS of REF was the lowest, and it was followed by the O1 at the initial day. However, the TBARS of O1 had the lowest value from 3 to 28 days of storage among all treatments. In addition, the TBARS of the OGTPSs was lower than that of freeze-drying at the same level of GTP. GTP dried by oven-drying had more total phenolics than those processed by freeze-drying, which could improve the oxidant activity. However, Dorta et al. (2012) did study on antioxidant activities of mango peel and seed by different drying treatments and they reported that mango seeds and peels could be stabilized by freeze drying without reducing antioxidant activities rather than the oven-drying. They explained that drying methods affected the contents of phenol and anthocyanin, which contribute to antioxidant activities. Drying is a useful technique for a longer shelf-life of fruits and vegetables with better antioxidant and antimicrobial activities, and freeze-drying can remove water from frozen material mainly by sublimation to preserve the product quality (Ratti, 2001). Oven-drying reduced the vitamin C content and increased the water-soluble R-tocopherol Trolox analog antioxidant content (Lavelli et al., 1999). Thus, GTP might be useful to the lipid antioxidant for regular-fat sausages during storage, especially the O1GTP is most influential among all treatments except for REF.

Total plate counts (TPC) and expressible moisture (EM, %)

The microbial counts of total bacteria and *Enterobacteriaceae,* and EM of the GTPSs are listed in Table 6. EM decreased with the addition of GTP except for F2, and the EM in all treatments showed a gradually decreasing trend during storage. However, no differences were observed except for the O2. These results indicated that the water-holding capacity during storage might maintain or increase in the O2. Kerr et al. (2005) reported that the EM means the degree of juiciness retention in cooked sausages, and they also claimed the EM might be low with high cooking loss. In this study, the cooking losses (%) for the CTL, REF, F1, F2, O1 and O2 groups were 6.7, 6.8, 6.8, 7.6, 7.5, and 7.1%, respectively, which showed opposite trends to the EM.

During storage, the total microbial counts increased rapidly up to 28 days of storage. The addition of GTP tended to reduce the microbial counts. The TPC of the O1 was not detected

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until 7 days of storage (< 10^2 cells/g), and had the lowest TPC among all treatments. Thus, the O had better antimicrobial activities than that of other sausages, and the O1 had the best effect on microbial inhibition. TPC was reduced by the addition of GTP and oven-dried tomato powder had better antimicrobial effects with lower microbial counts than freeze-dried GTP. This observation was consistent with those of Kim et al. (2011) and Osterlie and Lerfall (2005), who reported that the lower pH of sausages with tomato powder reduced the microbial counts, demonstrating effective antimicrobial activity. Similarly, dried fruits and vegetables inhibited the growth of spoilage microorganisms because lower water content and powerful antimicrobial enzymatic or non-enzymatic browning reactions also could have occurred in the material matrix (Zhang et al., 2006; Argyropoulos et al., 2011). No microbial counts for *Enterobacteriaceae* (VRB) were observed during the storage time. Thus, the application of OGTP to meat products could be beneficial because of its antimicrobial activity.

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Conclusion

Grape tomato powders improved the texture of regular-fat sausages and decreased pH, lightness, expressive moisture, total plate count, and thiobarbituric acid-reactive substances but increased the redness, yellowness and protein contents. More importantly, the regular-fat sausages added with oven-dried grape tomato powders decreased the TPC and TBARS more than those mixed with FGTP. In addition, reference treatments showed least level of TPC and TBARS among all treatments. Thus, regular-fat sausages added with oven-drying grape tomato powder had better lipid antioxidant and antimicrobial activities, and oven-dried GTP dried at 100 °C could be applied to meat products to extend shelf-life during storage time.

Conflicts of interest

The authors declare no potential conflicts of interest.

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Author Contributions

Conceptualization: ZhuangZhuang Qiu and Koo Bok Chin. Data curation: ZhuangZhuang Qiu and Koo Bok Chin. Formal analysis: ZhuangZhuang Qiu and Koo Bok Chin. Methodology: ZhuangZhuang Qiu and Koo Bok Chin. Software: ZhuangZhuang Qiu and Koo Bok Chin. Validation: ZhuangZhuang Qiu and Koo Bok Chin. Investigation: ZhuangZhuang Qiu and Koo Bok Chin. Writing - original draft: ZhuangZhuang Qiu. Writing - review & editing: Koo Bok Chin.

Ethics Approval

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This study did not require IRB/IACUC approval because there were no human or animal participants.

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Table 1. Formulation of pork RFSs with different drying methods and levels of grape tomato powders

Ingredient(%)	Treatments					
	Control	Reference	F1	F2	O1	O2
Raw meat	60.0	60.0	60.0	60.0	60.0	60.0
Fat	20.0	20.0	20.0	20.0	20.0	20.0
Water	18.0	18.0	18.0	18.0	18.0	18.0
Non-meat ingredient	2.0	2.0	2.0	2.0	2.0	2.0
Salt	1.3	1.3	1.3	1.3	1.3	1.3
Sodium tripolyphosphate	0.4	0.4	0.4	0.4	0.4	0.4
Cure blend	0.25	0.25	0.25	0.25	0.25	0.25
Sodium erythorbate	0.05	0.05	0.05	0.05	0.05	0.05
Ascorbic acid	-	0.1	-	-	-	-
Tomato powder	-	-	0.25	0.5	0.25	0.5
Freeze drying	-	-	0.25	0.5	-	-
100^{o}C oven drying	-	-	-	-	0.25	0.5
Total	100	100.1	100.25	100.5	100.25	100.5

Treatments: CTL = control; REF = reference (0.1% Ascorbic acid); F1 = sausages mixed with 0.25% of freeze drying grape tomato powder (≤ 150um mesh) (F1GTPSs); F2= sausages mixed with 0.5% of freeze drying grape tomato powder (≤ 150um mesh) (F2GTPSs); O1 = sausages mixed with 0.25% of oven dried grape tomato powder (≤ 150um mesh) at 100^{o}C oven (O1GTPSs); O2 = sausages mixed with 0.5% of oven dried grape tomato powder (≤ 150um mesh) at 100^{o}C oven (O2GTPSs);

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Table 2. pH and color value of pork RFSs as affected by different drying methods and levels of grape tomato powder

	Parameters			
Treatments	pH	CIE L^*	CIE a^*	CIE b^*
CTL	6.11^{a}	74.80^{a}	10.71^{d}	5.76^{e}
REF	6.10^{a}	73.50^{b}	11.40^{c}	5.77^{e}
F1	6.08^{b}	72.50^{bc}	12.62^{ab}	7.34^{d}
F2	6.07^{b}	73.00^{c}	12.73^{ab}	8.51^{c}
O1	6.05^{c}	67.00^{d}	12.31^{b}	12.35^{b}
O2	6.04^{c}	63.00^{e}	13.10^{a}	14.32^{a}
Storage days				
0	6.07^{B}	70.62^{A}	12.31^{A}	8.89^{A}
3	6.02^{C}	70.52^{A}	12.14^{A}	8.87^{A}
7	6.08^{B}	70.53^{A}	12.43^{A}	9.58^{A}
14	6.08^{B}	70.81^{A}	12.02^{A}	8.90^{A}
21	6.10^{A}	70.53^{A}	12.12^{A}	8.99^{A}
28	6.10^{A}	70.84^{A}	12.13^{A}	8.83^{A}

$^{a\text{-}f}$ Mean with different superscripts in the treatment are different ($p < 0.05$).

$^{A\text{-}D}$ Mean with different superscripts in the storage day are different ($p < 0.05$).

Parameters: CIE L^* = lightness; CIE a^* = redness; CIE b^* = yellowness.

Treatments: same as in Table 1

ACCEPTED

Table 3. Proximate composition of pork RFSs as affected by different drying methods and levels of grape tomato powder

	Parameters		
Treatments	**Moisture (%)**	**Fat (%)**	**Protein (%)**
CTL	64.3^{a}	19.3^{a}	13.9^{d}
REF	63.4^{a}	19.9^{a}	14.1^{cd}
F1	64.3^{a}	19.8^{a}	14.4^{bcd}
F2	64.5^{a}	19.5^{a}	14.6^{ab}
O1	63.0^{a}	20.9^{a}	15.0^{a}
O2	63.4^{a}	20.9^{a}	14.6^{abc}
Storage days			
0	65.2^{A}	18.6^{B}	14.7^{A}
3	64.1^{ABC}	19.6^{AB}	14.7^{A}
7	64.7^{AB}	20.2^{AB}	14.3^{AB}
14	62.8^{C}	20.2^{AB}	14.6^{AB}
21	62.6^{C}	20.9^{A}	14.1^{B}
28	63.4^{BC}	20.7^{A}	14.3^{AB}

$^{a\text{-}d}$ Means with different superscripts in the treatment are different ($p < 0.05$).
$^{A\text{-}C}$ Means with different superscripts in the storage time are different ($p < 0.05$).
Treatments: Same as in Table 1

ACCEPTED

Table 4. Textural profile properties of pork RFSs as affected by different drying methods and levels of grape tomato powder

	Parameters				
	Hardness (N)	**Springiness** (mm)	**Gumminess** (kg mm^{-1})	**Chewiness** (kg mm^{-1})	**Cohesiveness**
Treatments					
CTL	38.64^{a}	6.25^{b}	24.7^{a}	146^{a}	8.65^{b}
REF	25.71^{e}	5.85^{c}	22.6^{ab}	117^{bc}	8.12^{c}
F1	26.30^{e}	5.74^{c}	22.7^{ab}	117^{c}	8.27^{c}
F2	28.43^{d}	6.28^{b}	21.0^{b}	115^{c}	7.78^{d}
O1	30.27^{c}	6.37^{b}	23.8^{a}	125^{b}	8.17^{c}
O2	32.52^{b}	6.65^{a}	26.3^{a}	121^{bc}	9.78^{a}
Days					
0	27.67^{D}	6.29^{A}	21.4^{C}	118^{B}	8.75^{A}
3	31.88^{A}	6.03^{C}	25.4^{A}	138^{A}	8.53^{AB}
7	29.93^{C}	6.12^{BC}	22.0^{BC}	118^{B}	8.32^{B}
14	30.58^{BC}	6.11^{BC}	23.3^{ABC}	122^{B}	8.38^{B}
21	30.63^{BC}	6.31^{A}	22.9^{BC}	122^{B}	8.42^{AB}
28	31.19^{AB}	6.27^{AB}	24.3^{AB}	123^{B}	8.38^{B}

$^{a\text{-}d}$ Mean with different superscripts in treatment are different ($p < 0.05$).

$^{A\text{-}D}$ Mean with different superscripts in the storage time are different ($p < 0.05$).

Treatments: Same as in Table 1

ACCEPTED

Table 5. TBARS of pork RFSs as affected by different drying methods and levels of grape tomato powder

Parameters	Treatment	Storage (day)					
		0	3	7	14	21	28
TBARS (mg MAD/Kg)	CTL	0.2338^{fA}	0.2644^{eA}	0.3283^{dA}	0.4033^{cA}	0.4445^{bA}	0.4716^{aA}
	REF	0.1898^{bD}	0.1978^{abD}	0.1975^{abE}	0.2047^{abE}	0.2084^{aE}	0.2128^{aE}
	F1	0.2233^{fAB}	0.2472^{eB}	0.3079^{dB}	0.3433^{cB}	0.3810^{bB}	0.4026^{aB}
	F2	0.2033^{eC}	0.2360^{dB}	0.2595^{cC}	0.2858^{bC}	0.3110^{aC}	0.3275^{aC}
	O1	0.2090^{dC}	0.2191^{cdC}	0.2254^{cD}	0.2436^{bD}	0.2595^{aD}	0.2688^{aD}
	O2	0.2218^{fB}	0.2453^{eB}	0.2621^{dC}	0.2840^{cC}	0.3094^{bC}	0.3238^{aC}

$^{a\text{-}f}$ Mean with different superscripts in a same storage time are different ($p < 0.05$).
$^{A\text{-}E}$ Mean with different superscripts in the same treatment are different ($p < 0.05$).
Parameters: TABRS= thiobarbituric acid-reactive substances (mg MAD/Kg)
Treatments: Same as in Table 1

ACCEPTED

Table 6. Changes of expressive moisture and microbial counts of pork RFSs as affected by different drying methods and levels of grape tomato powder

Parameters	Treatments	Storage (day)					
		0	3	7	14	21	28
EM	CTL	21.14^{aBC}	21.42^{aA}	20.18^{aB}	20.61^{aA}	20.10^{aA}	19.50^{aA}
	REF	21.63^{aB}	19.60^{bcAB}	22.26^{aA}	19.69^{bA}	19.43^{bcA}	18.20^{cAB}
	F1	19.65^{aCD}	17.51^{bBC}	17.76^{abD}	19.01^{abA}	17.75^{abA}	17.68^{abAB}
	F2	23.58^{aA}	18.06^{bBC}	19.65^{bBC}	19.83^{bA}	18.03^{bA}	17.67^{bAB}
	O1	19.19^{abD}	16.89^{bC}	18.90^{abCD}	20.92^{aA}	19.00^{abA}	18.82^{abAB}
	O2	19.66^{abCD}	18.20^{abBC}	20.55^{aB}	20.31^{abA}	20.01^{abA}	17.28^{bB}
TPC	CTL	$<2^{fA}$	3.30^{eA}	$3.83d^{A}$	4.74^{cA}	5.08^{bA}	5.83^{aA}
	REF	$<2^{fA}$	2.95^{eC}	3.56^{dBC}	4.21^{cB}	4.53^{bB}	4.69^{aC}
	F1	$<2^{fA}$	3.24^{eB}	3.66^{dB}	4.26^{cB}	4.54^{bB}	4.79^{aB}
	F2	$<2^{fA}$	2.99^{dC}	3.46^{cCD}	4.05^{bBC}	4.32^{bBC}	4.69^{aC}
	O1	$<2^{dA}$	$<2^{dE}$	$<2^{dE}$	3.50^{cD}	3.95^{bD}	4.45^{aD}
	O2	$<2^{fA}$	2.58^{eD}	3.33^{dD}	3.94^{cC}	4.26^{bD}	4.52^{aD}

$^{a-f}$ Mean with different superscripts in a same treatment are different ($p < 0.05$).

$^{A-E}$ Mean with different superscripts in the same storage day are different ($p < 0.05$).

Parameters: EM=expressive moisture; TPC=total bacterial counts (Log CFU/g);

Treatments: Same as in Table 1

ACCEPTED

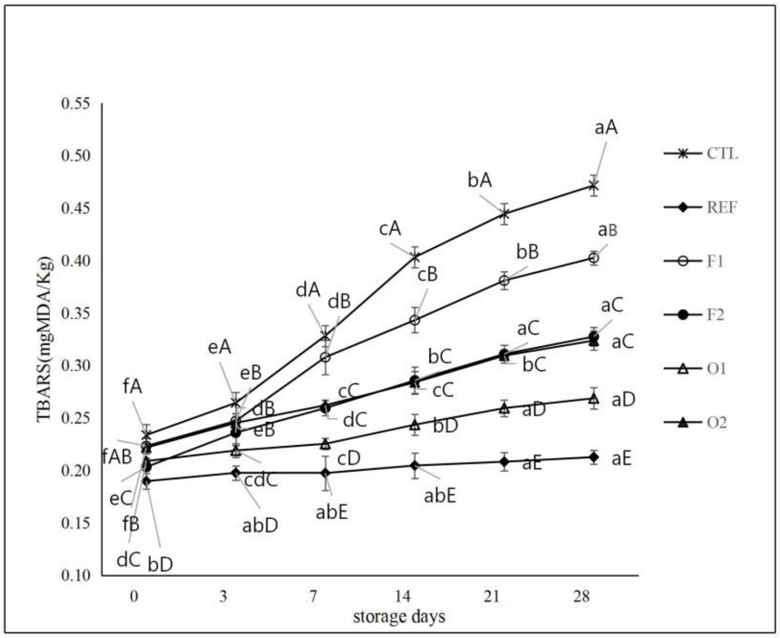

Figure 1. TBARS of regular sausages as affected by different drying methods and levels of grape tomato powder

[a-f] Mean with different superscripts in the same storage time are different ($p < 0.05$).

[A-E] Mean with different superscripts in a same treatment are different ($p < 0.05$).

Treatments: CTL = control; REF = reference (0.01% Ascorbic acid); F1 = sausages mixed with 0.25% of freeze drying small tomato powder (≤ 150um mesh) (F1GTPSs); F2= sausages mixed with 0.5% of freeze drying small tomato powder (≤ 150um mesh) (F2GTPSs); O1 = sausages mixed with 0.25% of oven dried small tomato powder (≤ 150um) at 100℃ oven (O1GTPSs); O2 = sausages mixed with 0.5% of oven dried small tomato powder (≤ 150um mesh) at 100℃ oven (O2GTPSs);