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Effects of tomato peel as fat replacement on the texture, moisture migration, and sensory quality of sausages with varied fat levels

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ABSTRACT

The influence of tomato peel powder on the water holding capacity, microstructural character, and sensory quality of reduced-fat sausages during storage was investigated. In this work, rough tomato peels were crushed to powders of 0.15- and 0.025-mm particle sizes by conventional crushing and airflow ultramicro-crushing, respectively. Replacing fat with tomato powder significantly increased the amount of free water in sausages after storage, as determined by low-field nuclear magnetic resonance imaging. However, less free water was present in sausage samples that were already of the reduced-fat variety. Sausages with the conventional mechanically crushed tomato powder showed denser and more compact structures than sausages with those using the airflow ultramicro-crushed powder. Compared to the case of sausages with higher levels (3%) of tomato peel, granulation was more obvious (p < 0.05) in samples with lower levels of tomato peel (0.5%), and more pores were observed in the samples with higher tomato powder content. The results indicated that low doses of conventionally crushed tomato powder as a potential fat substitute could be used in the sausage industry.

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Fat replacement; microstructure character; food quality control; low-field NMR

1. Introduction

Research has shown that excessive consumption of animal fats may contribute to chronic disorders, such as cardiovascular disease, obesity, and fatty liver; thus, their consumption should be limited (Choi et al., 2009; Pereira & Vicente, 2013). When an individual eats excessively fatty foods, such as meats that are rich in cholesterol and saturated fatty acids, the chances of that individual developing chronic health disorders increases significantly (Ferguson, 2010; McAfee et al., 2010). To help reduce the risk of cardiovascular disease, reducing the intake of fat or replacing fats with nonfatty components in foods has been suggested. Recently, food scientists have successfully developed new formulations of food products containing less fat than their traditional counterparts (Cardoso, Mendes, & Nunes, 2008; Choi et al., 2014; Rezende, Benassi, Vissotto, Augusto, & Grossmann, 2015). In this way, they have minimized the possibilities of developing health risks associated with excessive consumption of high-fat foods (Carrapiso,
Jurado, Martin, & Garcia, 2007; Mendoza, Garcia, Casas, & Selgas, 2001). However, fats are important contributors to the texture, flavor, mouthfeel, and perceived juiciness of meat products (Ayo et al., 2007; Wang, Zhao, Ren, Fan, & Wu, 2013). Excessive reduction in fat content can greatly alter the structural properties of food. For example, the appearance of fermented sausages with olive oil instead of pork fat was unappealing because of the wrinkled surfaces and hardened cases (Koutsopoulos, Koutsimanis, & Bloukas, 2008, Muguerza, Fista, Ansorena, Astiasaran, & Bloukas, 2002). High-fat foods maintain higher sensory scores in appearance, texture, flavor, and other characteristics. Hence, in preparing low-fat foods, it is necessary to reduce the animal fat proportion by using non-lipid fat substitutes that minimize the faults associated with the texture of low-fat foods.

Dietary fiber (DF) is considered a leftover of edible plant cells, a largely indigestible and low-calorie ingredient. Certain fibers can be appropriate fat replacements in meat emulsion products because they show excellent water holding capacity (Hughes, Cofrades, & Troy, 1997). In addition, DF promotes several biological activities that benefit the absorption of essential nutrients (González Canga et al., 2004; Zhang et al., 2001). Hence, numerous studies have discussed the use of DF as a promising healthier alternative in the production of low-fat meats. Grigelmo-Miguel, Abadías-Serós, and Martín-Bellosa (1999) showed that the sensory properties of traditional meat products were maintained when peach DF and water were added to meat batters. Mendoza et al. (2001) found that the addition of powdered inulin, a functional and soluble DF, to a sausage formulation produced the best sensory effects; the products achieved significantly higher acceptance scores than the control low-fat products that did not contain inulin. Furthermore, the addition of DF, inulin, and gel from fruits and cereals created satisfactory outcomes as the amount of fat was reduced in fermented sausages (García, Domínguez, Galvez, Casas, & Selgas, 2002; Salazar, García, & Selgas, 2009).

Tomato peel, an undervalued agro-industrial waste, contains nondigestible fiber with numerous physiological effects and therapeutic applications (González Canga et al., 2004; Majzoobi, Ghavi, Farahnavy, Jamalian, & Mesbahi, 2011). Previously, our group demonstrated that crushed tomato peel powder functioned as an excellent fat substitute in sausages (Wang et al., 2015). The results showed that the incorporation of tomato peel powder in the formulation successfully reduced the total amount of animal fat by 0.5–3.0% (w/w), improved the fatty acid composition profile, and decreased the lipid oxidation in the final product. However, this research mainly focused on the influence of tomato peel as a fat substitute on the fatty acid composition and oxidative stability of sausage. Thus, to fully understand the role of tomato peel powder on the stability of sausage, further studies are needed to elucidate the microstructure and potential mechanism of fiber replacement in low-fat meat products. The primary objectives of this study were to investigate: (1) the microstructural character and water binding capacity of sausages with tomato peel powders treated by different processes, resulting in different particle diameters; (2) the level of tomato peel powder that acts as a moisture additive while minimizing decreases in the sensory acceptability; and (3) the consumer sensory evaluation of sausages using tomato peel powder.

2. Materials and methods

2.1. Materials

Tomato peel, a tomato juice industry waste, was provided by Xinjiang Tianye Co., Ltd. The fresh tomato peel was dehydrated on trays in a pilot-scale hot-air drier. After drying, the tomato peel was crushed using two methods: (1) conventional mechanical crushing (CMC): rough tomato peels were crushed to powder with 0.15-mm particles by conventional crushing equipment (model XFB-100, Hebi Equipment Co., Ltd, China); (2) airflow ultramicro-crushing (AUC): the rough tomato peels were crushed to powder with 0.025-mm particles by the AUC equipment model LNJ-6A (Mianyang Liuneng Powder Equipment Co., Ltd, China).

2.2. Sausage preparation

Fresh boneless beef, pork fat, and boneless pork shoulder were obtained from a local supermarket. The beef, trimmed of visible fat, and pork fat attached to the skin were mixed together. Both beef and pork fat were weighed and properly tempered; all the raw materials to be used were kept at 5°C for 24 h.

The sausage processing was performed as described by Zhang, Lin, Leng, Huang, and Zhou (2013) and Muguerza et al. (2002) with modifications to the formula. The six types of sausages prepared had three different levels of fat content (30%, 15%, and 5%, w/w); at each of these levels, pork fat was replaced with tomato peel (10%, w/w). The formulation of raw materials is presented in Table 1. All treatment procedures were performed in triplicate. The frozen beef and pork meat were slowly cut, weighed, and chopped for 3 s using a cutter. Then, the chopped meat was mixed with all the abovementioned ingredients, excepting sodium chloride. The pork fat and pre-emulsified fat were added, and the resulting meat mixture was chopped for 3 s. Then, sodium chloride was added to the

| Table 1. Product formulation for different sausage ingredients. |
| --- |
| Treatment | Lean beef | Lean pork | Pork back fat | Tomato peel powder |
| HFN | 300 | 400 | 300 | 0 |
| LFN | 250 | 700 | 50 | 0 |
| HFC | 300 | 400 | 270 | 30 |
| LFC | 250 | 700 | 45 | 5 |
| HFA | 300 | 400 | 270 | 30 |
| LFA | 250 | 700 | 45 | 5 |

HFN: High fat with no tomato peel powder; LFN: low fat with no tomato peel; HFC: high fat with CMC tomato peel powder; LFC: low fat with CMC tomato peel powder; HFA: high fat with AUC tomato peel powder; LFA: low fat with AUC tomato peel powder.

Alto contenido graso sin piel de tomate en polvo (HFN); Bajo contenido graso sin piel de tomate en polvo (LFN); Alto contenido graso con piel de tomate en polvo triturada mediante mecanismo convencional (HFC); Bajo contenido graso con piel de tomate en polvo triturada mediante mecanismo convencional (LFC); Alto contenido graso con piel de tomate en polvo pulverizada mediante trituración ultramicro con flujo de aire (HFA); Bajo contenido graso con piel de tomate en polvo triturada mediante trituración ultramicro con flujo de aire (LFA).
meat mixture. Finally, this meat mixture was slowly chopped to the desired particle size of ~3–5 mm. After chopping, a vacuum stuffer was used to immediately stuff the prepared sausage mixture into collagen casings of 50 mm in diameter. Sausages were hand linked to standard weights of 0.5–1.0 kg each, and the resultant strings of sausages were refrigerated for up to 48 days at 4°C, similar to storage conditions experienced in a supermarket. Samples prepared from each treatment procedure were taken for analysis on days 0, 12, 36, and 48. Each sausage formula, with and without tomato peel powder, was divided into six samples as follows: high-fat (HFN), low-fat (LFN), high-fat with AUC tomato peel powder (HFA), low-fat with AUC tomato peel powder (LFA), high-fat with CMC tomato peel powder (HFC), and low-fat with CMC tomato peel powder (LFC).

2.3. Chemical analysis

Fat and ash were determined according to standard AOAC (1990) procedures. Data presented are means of three measurements. Soluble and insoluble fiber levels were quantified by the enzymatic–gravimetric method of Asp, Johansson, Hallmer, and Siljestroem (1983).

2.4. Color measurement

Color measurements were performed using a colorimeter with the D65 illuminant (UltraScan PRO, Hunterlab, USA). Three measurements for each analytical point were performed. \(L^*\) (lightness), \(a^*\) (redness), and \(b^*\) (yellowness) scale coordinates were plotted. To compare the overall color changes between the DF-supplemented sausage samples and control, the total color differences (\(\Delta E\)) between the samples (\(L_a, a_b, b_c\)) and the control (\(L_0, a_0, b_0\)) were calculated as shown below (Femenia, Lefebvre, Thebaudin, Robertson, & Bourgeois, 1997):

\[
\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}
\]

For each sample, measurements were taken on different areas of the surfaces of four different slices. Five consecutive measurements were taken for each sample. Before each series of measurements, the instrument was calibrated using a white ceramic tile.

2.5. Scanning electron microscopy

Scanning electron microscopy (SEM) analysis was performed as described by Chang, Wang, Zhou, Xing-Lian, and Chun-Bao (2010) with modifications. The SEM evaluation method was used to determine microstructural changes in the samples. To observe the samples by SEM, 5 × 5 × 3 mm slices were removed from the original steaks, perpendicular to the muscle fiber. Then, the slices were placed in a 0.1-M phosphate buffer solution and fixed in 2.5% glutaraldehyde (v/v, \(pH = 7\)) after cooling to 4°C. Then, the gradient ethanol dehydration series (30, 50, 70, 90, and 100%) was used for 20 min on each solution at room temperature. Finally, they were placed in ethanol three times for 30 min each. Then, the samples were placed in triplicate with tert-butanol cement. After freeze-drying, sputtered gold films (10 nm) were applied to the specimens and examined during the shooting of a SEM (S-3000N/H, Hitachi High Technologies Ltd., Japan) at an acceleration voltage of 20 kV. Micrographs of 500× magnification were obtained to observe the samples.

2.6. Nuclear magnetic resonance analysis

For the nuclear magnetic resonance (NMR) measurements, a low-field MNIMR60 (Niumag Corporation, China) benchtop NMR analyzer with a working frequency of 23.321 MHz and a magnetic field strength of 0.55 T was utilized. Test tubes of 60 mm in width were used in the study. Relaxation-time measurements were performed on the samples in the experiment. The transverse relaxation time (T2) used the analysis software with the Carr–Purcell–Meiboom–Gill (CPMG) Magnetic Resonance Imaging pulse sequence. T2 was measured on the radio-frequency (RF) coil permanent magnetic field at the center position of the collection. The sequence parameters were set to:

- \(TD = 139212\), \(SW (kHz) = 200\), \(D3 (\mu s) = 800\), \(RG1 = 20\), \(RG2 = 3\), \(NS = 4\), \(EchoTime (\mu s) = 100\), \(EchoCount = 3000\), interpulse spacing of 100 μs, 90-degree pulse time P90 = 17 μs, 180-degree P180 = 32 pulse times. For the CPMG measurements, 3000 measuring points were used. Four replicates were made from each sample group.

2.7. Sensory evaluation

Sensory evaluation was conducted according to a procedure prescribed by Stone and Sidel (2007) as follow: Briefly, 20 trained panelists were recruited from the staff and students of the Chongqing University of Education, Chongqing, China. Panelists were chosen based on previous experience in consuming similar sausages. A preparatory meeting was held before the test in order to ensure that the method for the testing process was understood by all of the panelists. After testing, the team members agreed with the proposed specifications. These members also conducted descriptive and quantitative analyses. During the evaluation process, the team members were placed in private booths having incandescent lamps of approximately 350 lx in strength. Rectangular pieces of approximately 1.5 × 2 cm were cut from the centers of the sausage slices and served at room temperature. Each panelist evaluated three replicates for every treatment group; the order of sample presentation was randomized for each panelist. Tap water was used to clean the tongues and hands of the panelists while providing different samples.

2.8. Statistical analysis

In this study, three batches of sausages were made and all measurements were done in triplicate. Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL). A one-way analysis of variance combined with Duncan’s multiple-range test was conducted to determine the significant differences between fat-reduced sausages with and without tomato fiber content. Effects were considered significant at \(p < 0.05\) (*) and \(p < 0.01\) (**).
3. Results and discussion

3.1. Physical and chemical properties

In Table 2, the particle size and DF contents of the tomato peel powders treated by CMC and AUC are analyzed. Although the total DF content of the tomato peels is approximately 68% (w/w), the soluble DF content (14.04%, w/w) in the AUC tomato powder was higher than that (5.72%, w/w) with CMC. It can be concluded that the AUC method could improve the content of soluble DF in tomato peel powder, because the percentage of soluble DF was significantly (p < 0.05) increased with a decrease in particle size.

Physical and chemical analyses of the sausages mixed with tomato peel powders prepared by the two treatments are presented in Table 3. Differences in the moisture and ash of the most varied sausages are statistically significant (p < 0.05) from 0 to 48 days of storage. All samples mixed with tomato peel powder showed similar properties, with higher moisture contents than the unmixed groups at the end of the storage period. These results suggest that samples with added tomato powder have higher locked moisture than the non-tomato powder samples. Pereira et al. (2011) and Yang, Choi, Jeon, Park, and Joo (2007) also reported that the addition of collagen, fibers, and rice bran to low-fat pork sausage increased the water-binding capacity, which could benefit the texture and quality. The ash contents of the batters formulated with tomato peel powder were higher in all test batters relative to the control because of the existence of tomato fiber. These results indicate that adding tomato powder had an effect on the increase of ash content in the sausage. No significant differences (p > 0.05) in protein content were found in all sausage samples during storage, and the protein content was higher in batters formulated with tomato DF than the control sample because the protein content of tomato fiber was 10.21% (Table 2). The control has higher fat content than the sample with tomato fiber. This condition is not surprising because the control sausage contained 30% pork back fat, whereas other batters contained 10% tomato fiber-replaced fat. Beef patties with higher initial fat content are reported to create larger fat pools, which helps fat to migrate out of the inner into the outer part of the beef fatty, whereas water losses are substantially less influenced by different raw materials (Kovács, Landes, Hamscho, Döbert, & Menzel, 2005; Salazar et al., 2009).

3.2. Color evolution

Lightness (L*), redness (a*), and yellowness (b*) are considered the most informative parameters for color changes (Mielnik & Slinde, 1983). Compared with the control samples (HFN and LFN), the sausages with different diameters of tomato peel powder samples (HFC, LFC, HFA, and LFA) experienced sharp color differences, as reported in Table 4. In the early days, the L* and a* values of sausages containing AUC tomato powder were lower than those of the control groups (HFN and HFC), but the b* values were significantly higher (p < 0.05) than control groups. This situation persisted until day 36. The b* values of the sausages were found to increase with an increasing amount of tomato powder, indicating that the sausage became more yellowish with the addition of AUC tomato powder. This could be attributed to the high b* value of AUC tomato peel powder. However, the L* values of sausages containing CMC tomato powder were close to those of the control groups, apart from HFA. Excepting HFA and LFA, in samples containing higher fat levels, such as HFN and HFC, the color of the sausages was lighter (higher L* value) than that of samples containing lower fat levels (LFN and LFC) at 0 day.

L* seems to be the most informative parameter for color changes in meat and meat products (Bozkurt & Bayram, 2006). Comparing the color values from Figure 1 and Table 4, the

### Table 2

| Treatment                 | Particle size (mm) | Insoluble dietary fiber | Soluble dietary fiber |
|---------------------------|--------------------|-------------------------|----------------------|
| Conventional mechanical   | =0.150a            | 62.63 ± 3.53a           | 5.72 ± 0.25a         |
| Airflow ultramicro        | =0.025b            | 54.27 ± 2.52b           | 14.04 ± 1.33b        |

Results are expressed as the mean ± SE; data are the mean of three replicates.

Data with identical lowercase letters for the same parameter indicate no significant difference at p > 0.05 in the same column.

Los datos acompañados de letras minúsculas idénticas para el mismo parámetro indican que no existe una diferencia significativa a p > 0.05 al interior de la misma columna.

### Table 3

| Parameters | Sausage type | Sausage storage time (days) | p | Δ |
|------------|--------------|-----------------------------|---|---|
| Moisture   | HFN          | 31.33 ± 1.37                | 27.08 ± 1.82 | * | I |
|            | LFN          | 33.10 ± 1.42                | 25.62 ± 1.70 | * | I |
|            | HFA          | 34.17 ± 1.02                | 37.34 ± 1.30 | * | T |
|            | LFA          | 32.67 ± 0.88                | 31.55 ± 0.59 | - | I |
|            | HFC          | 33.84 ± 2.78                | 38.70 ± 1.73 | * | T |
|            | LFC          | 31.20 ± 1.15                | 34.26 ± 1.25 | * | T |
| Ash        | HFN          | 7.52 ± 0.08                 | 8.08 ± 0.53   | - | T |
|            | LFN          | 5.35 ± 0.11                 | 6.40 ± 1.03   | - | T |
|            | HFA          | 4.80 ± 0.53                 | 3.22 ± 0.40   | - | T |
|            | LFA          | 12.00 ± 0.52                | 15.52 ± 0.95  | * | T |
|            | HFC          | 19.59 ± 1.53                | 13.87 ± 0.79  | * | T |
|            | LFC          | 19.14 ± 2.97                | 22.46 ± 1.30  | * | T |

All values are the mean ± standard deviation of three replicates. Column with p reflects the significant difference between 0 and 48 days (*p < 0.05; **p < 0.01; ***p > 0.05). Column with Δ reflects the trends of parameters between 0 and 48 days (T’ increased; ‘ I’ decreased). Data with identical lowercase letters (a, b, c, d and e) for the same parameter indicated no significant difference at p > 0.05 within the same column.

Todos los valores son la media ± la desviación estándar de tres réplicas. La columna indicada con la p refleja la diferencia significativa entre 0 d y 48 d (*p < 0.05; **p < 0.01; ***p > 0.05). La columna indicada con Δ refleja las tendencias de los parámetros entre 0 d y 48 d (I’ aumentó; ‘ I’ disminuyó). Los datos con letras minúsculas idénticas (a, b, c, d y e) para el mismo parámetro no indicaron diferencia significativa en p > 0.05 dentro de la misma columna.

### Table 4

| Parameters     | Sausage type  | Moisture (g/100 g) | Fat (g/100 g) | Protein (g/100 g) |
|----------------|---------------|--------------------|---------------|-------------------|
|                | HFN           | 31.33 ± 1.37       | 27.08 ± 1.82  | 8.63 ± 0.62       |
|                | LFN           | 33.10 ± 1.42       | 25.62 ± 1.70  | 18.55 ± 1.43      |
|                | HFA           | 34.17 ± 1.02       | 37.34 ± 1.30  | 24.19 ± 3.42      |
|                | LFA           | 32.67 ± 0.88       | 31.55 ± 0.59  | 25.40 ± 0.76      |
|                | HFC           | 33.84 ± 2.78       | 38.70 ± 1.73  | 17.10 ± 1.53      |
|                | LFC           | 31.20 ± 1.15       | 34.26 ± 1.25  | 16.44 ± 0.99      |
|                | HFN           | 7.52 ± 0.08        | 8.08 ± 0.53   | 7.26 ± 0.19       |
|                | LFN           | 5.35 ± 0.11        | 6.40 ± 1.03   | 13.53 ± 2.42      |
|                | HFA           | 4.80 ± 0.53        | 3.22 ± 0.40   | 12.76 ± 0.36      |
|                | LFA           | 12.00 ± 0.52       | 15.52 ± 0.95  | 35.22 ± 2.02      |
|                | HFC           | 19.59 ± 1.53       | 13.87 ± 0.79  | 19.59 ± 1.52      |
|                | LFC           | 19.14 ± 2.97       | 22.46 ± 1.30  | 24.47 ± 2.36      |

Results are expressed as the mean ± SE; data are the mean of three replicates. Data with identical lowercase letters for the same parameter indicate no significant difference at p > 0.05 in the same column.

Los resultados son expresados como la media ± DE; el dato representa la media de tres réplicas. Los datos acompañados de letras minúsculas idénticas para el mismo parámetro indican que no existe una diferencia significativa a p > 0.05 al interior de la misma columna.
Changes in \( L^*, a^*, \) and \( b^* \) values during the ripening of Chinese sausages with different diameters of tomato peel powder.

### Table 4.

| Time (days) | \( L^* \) (0.05) | \( a^* \) (0.05) | \( b^* \) (0.05) |
|-------------|-----------------|-----------------|-----------------|
| 0           | 61.94 ± 0.26    | 60.13 ± 0.26    | 10.25 ± 0.26    |
| 24          | 60.70 ± 0.36    | 59.53 ± 0.36    | 9.46 ± 0.36     |
| 36          | 61.32 ± 0.26    | 59.83 ± 0.26    | 9.71 ± 0.26     |

All values were the mean ± standard deviation of three replicates. Data with identical lowercase letters for the same parameter indicated no significant difference at \( p > 0.05 \). The \( \Delta L^* \), \( \Delta a^* \), and \( \Delta b^* \) values of sausage groups with added AUC tomato powder (HFA and LFA) were significantly higher \((p < 0.05)\) than those of HFC and LFC. Thus, it might be a promising option to adjust the color of sausage by adding differently treated tomato peel powder, which may be a good choice as a partial substitute for nitrite (Wang et al., 2015).

### 3.3. Microstructural character

As shown in Figure 2(a–f), the SEM micrographs illustrate the microstructural changes in the transverse sections of the sausages containing different fat and tomato fiber contents. The existence form of the muscle fiber network is indicated by the arrows. A dense and fragmented structure is easily observed in the sausage with low-fat levels (Figure 2(b)). Compared to samples with lower fat (LF), the sausages with higher fat levels (HF) contain continuous and loose features in the microstructures of muscle bundles and muscle fibers. Collagen fibers in the HF samples have complex structures in which fibers of various striations cross each other to form a continuous shape. This effect could be attributed to either the HF amount or a steady collagen system. Compared to the sausages with higher levels of tomato peel (Figure 2(d,f)), granulation and cracking are more obvious in the samples with lower levels of tomato peel (Figure 2(c,e)).

In the formulations with mixed tomato peel powder, more pores are observed in the samples with higher tomato peel powder contents (Figure 2(c,e)). The higher proportion of empty spaces can be interpreted as additional water, possibly from the lower fat content and the added fiber, similar to those obtained by Felisberto, Galvao, Picone, Cunha, and Pollonio (2015). The fat in sausage is important in maintaining continuous muscle fibers. Because it repels water, fat in sausage could strengthen the structure. However, the soluble DF...
content in the tomato powder treated by AUC is higher than that with CMC (Table 2), providing better water-holding capacity, which is useful for reducing the hardness and network disruption of the sausage. One possible explanation is that the network disruption is weakened in samples with high doses of soluble DF from tomato powder, which may have acted similarly to a detergent in the matrix by interfering with protein crosslinking (Ktari, Smaoui, Trabelsi, Nasri, & Salah, 2014).

Although the SEM micrographs show no significant differences between the HFA (Figure 2(c)) and HFC (Figure 2(e)), these micrographs demonstrate that the sausage with CMC tomato peel powder has a denser and more compact structure than the formulations mixing AUC tomato peel powder. This is likely because the CMC tomato peel powder has larger particles and greater viscosity. These properties could help to explain the phenomenon observed in our previous work (Wang et al., 2015) in which the cohesiveness of samples with CMC tomato peel was better than that of samples with AUC tomato peel (data not shown).

### 3.4. Low-field NMR relaxation analysis

Low-field NMR is an effective nondestructive and noninvasive measurement technology to explain the variation of water in a sample from a microscopic point of view (Pearce, Rosenvold, Andersen, & Hopkins, 2011). Moisture in food can be divided into three forms: bound water, semi-bound water, and free water. Each curve inversion of the T2 spectrum has ~3–4 peaks, representing different states of water present in the sample, such as T21 (0.01–1 ms), T22 (5–13 ms), T23 (13–180 ms), and T24 (>180 ms). T21, T22, T23, and T24 separately represent strongly bound water, weakly bound water, easily flowing water, and free water. T24, which can be removed from food by drying, comprises mainly the structure of water present in vacuoles, protoplasm, and cell gaps. The total number is proportional to the amplitude of the signal in a sample proton NMR spectrum. Thus, the amount of moisture in the sample and its migration status could be indirectly reflected by analyzing the spectrum of T2 inversion. Most water in the sausage is easily flowing (T23), as shown in Figure 3. The results show that the degree of freedom of the

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**Figure 2.** (a–f) SEM photographs of sausages with differently treated tomato peel powder at 48-day storage. (a) High fat (HFN); (b) low fat (LFN); (c) high fat with AUC tomato peel powder (HFA); (d) low fat with AUC tomato peel powder (LFA); (e) high fat with CMC tomato peel powder (HFC); (f) low fat with CMC tomato peel powder (LFC). Yellow arrows indicate the presence of the muscle fiber networks in different sausage samples.

**Figura 2.** (a)–(d) Fotografías MEB de salchichas de distinto diámetro con contenido de piel de tomate en polvo tras 48 d de almacenaje. (a) Alto contenido graso (HFN); (b) bajo contenido graso (LFN); (c) alto contenido graso con piel de tomate en polvo pulverizada mediante trituración ultramicro con flujo de aire (HFA); (d) bajo contenido graso con piel de tomate en polvo triturada mediante trituración ultramicro con flujo de aire (LFA); (e) alto contenido graso con piel de tomate en polvo triturada mediante mecanismo convencional (HFC); (f) bajo contenido graso con piel de tomate en polvo triturada mediante mecanismo convencional (LFC). Las flechas amarillas indican la presencia de las redes de fibra muscular en diferentes muestras de salchichas.
immobilized water is increased and the bulk water is reduced gradually. With increased storage time, T21 (strongly bound water) undergoes no significant changes, while T22 (half-bound water) and T23 (easily flowing water) are significantly decreased, and T24 (free water) significantly increased in 48 days of storage. These data indicate that weakly bound water is partially converted to free water during sausage storage. It could be that the binding force between the easily flowing water and the sausage macromolecules is decreased with extended storage. This hypothesis is similar to that of Han, Wang, Xu, and Zhou (2014), who proposed that the changes in T22 could suggest that the free water molecules in the gel system are expelled during the gelation process, thereby increasing the molecular mobility of free water. In addition, the data also show that the addition of tomato peel powder can partly inhibit the increase of free water, which leads to excellent water retention in the sausage during storage. This should be considered as the best proof for the effect of tomato powder on the sausage microstructure by improving the water retention of the sausage.

NMR spectra of the proton density reflect the number of protons in the sample. Areas of greater brightness correspond to brighter projected proton images and redder pseudo-color images. The water distribution in the sample space can be intuitively followed in the proton density images. Figure 4 clearly shows that, with the extension of the storage time, the distribution of free water in the sausage samples differs significantly. In a comparison of the water contents of different samples over 48 days, it is found that the content of free water in each sample is increased overall. Increases of free water in the HFC and HFA samples are greater, showing greater brightness in Figure 4, than those in the LFC and LFA samples. This shows that high doses of the tomato skin powder reduce the compactness of the half-bound water and the large molecular substances in the sausage and change half-bound water to free water. Therefore, the addition of high doses of tomato skin powder could improve the free water content in the

![Figure 3](image1.png)

**Figure 3.** (a–b) Distribution of LF NMR T2 relaxation times in sausages with differently treated tomato peel powder at 0 and 48-day storage. (a) High fat (HFN); (b) low fat (LFN); (c) high fat with airflow ultramicro crushed tomato peel powder (HFA); (d) low fat with airflow ultramicro crushed tomato peel powder (LFA); (e) high fat with conventional mechanically crushed tomato peel powder (HFC); (f) low fat with conventional mechanically crushed tomato peel powder (LFC).

![Figure 3](image2.png)

**Figura 3.** (a–b) Distribución de RMN de CB de tiempos de relajación T2 en salchichas de distinto diámetro con contenido de piel de tomate en polvo. (a) Alto contenido graso (HFN); (b) bajo contenido graso (LFN); (c) alto contenido graso con piel de tomate en polvo pulverizada mediante trituración ultramicro con flujo de aire (HFA); (d) bajo contenido graso con piel de tomate en polvo triturada mediante trituración ultramicro con flujo de aire (LFA); (e) alto contenido graso con piel de tomate en polvo triturada mediante mecanismo convencional (HFC); (f) bajo contenido graso con piel de tomate en polvo triturada mediante mecanismo convencional (LFC).

![Figure 4](image3.png)

**Figure 4.** MRI imaging of sausages with differently treated tomato peel powder at 0 and 48-day storage. (a): High fat (HFN); (b) low fat (LFN); (c) high fat with AUC tomato peel powder (HFA); (d) low fat with AUC tomato peel powder (LFA); (e) high fat with CMC tomato peel powder (HFC); (f) low fat with CMC tomato peel powder (LFC).

![Figure 4](image4.png)

**Figura 4.** Imágenes por RM de salchichas de distinto diámetro con contenido de piel de tomate en polvo a los 0 d y 48 d de almacenamiento. (a) Alto contenido graso (HFN); (b) bajo contenido graso (LFN); (c) alto contenido graso con piel de tomate en polvo pulverizada mediante trituración ultramicro con flujo de aire (HFA); (d) bajo contenido graso con piel de tomate en polvo triturada mediante trituración ultramicro con flujo de aire (LFA); (e) alto contenido graso con piel de tomate en polvo triturada mediante mecanismo convencional (HFC); (f) bajo contenido graso con piel de tomate en polvo triturada mediante mecanismo convencional (LFC).
product during sausage storage, which confirms the T2 inversion trend shown in Figure 3.

3.5. Sensory evaluation

Sensory evaluation is used as an efficient way to gain consumer insights regarding meat products; therefore, food scientists (Mora-Gallego, Guardia, Serra, Gou, & Arnau, 2015) have used this feedback to devise improvements to the manufacture of meat products. Figure 5(a–e) displays the mean values of different sensory attributes (overall acceptability, appearance, flavor, taste, and color) as scored by each consumer. After 48 days of storage, the overall HFC and HFA groups receive the lowest scores from most consumers ($p < 0.05$), which reflects that the excessive addition of tomato peel powder also decreases the sensory evaluation of LF sausages. Regarding the color score, significant variance is detected between the control groups and the sausages with different diameters of tomato peel particles (Figure 5(a)). The results indicate that the color score of the control group is significantly higher than those of other groups, especially the HFC and HFA groups ($p < 0.05$); this shows that the optical evaluation of the potential consumer is influenced by the addition of tomato peel powder to sausages. It is clear that the color and appearance parameters of the control groups (HFN and LFN) are better than those of the groups containing tomato peel powder (Figure 5(a,b)). However, the appearance scores of LFC and LFA are higher than those of the groups with higher doses of tomato peel powder. A probable explanation is that HFC and HFA have more intensively wrinkled surfaces because of the excellent water-holding capacity of the tomato fiber, present in high amounts in these samples. According to the sensory scores, the tomato fiber level does not affect ($p > 0.05$) the taste of sausages in this study (Figure 5(c)). Apart from HFA, there are no differences in the high-fat groups and low-fat groups.

Figure 5. (a)–(e) Sensorial evaluations of sausages with differently treated tomato peel powder. Identical letters on the same day indicate the absence of significant differences at $p > 0.05$.

Figura 5. (a)–(e) Evaluaciones sensoriales de salchichas de distinto diámetro con contenido de piel de tomate en polvo. Las letras idénticas asociadas al mismo día indican que no existen diferencias significativas a $p > 0.05$. 
4. Conclusion

The AUC method for crushing tomato peel can improve the content of soluble DF in tomato peel powder; the percentage of soluble DF increased significantly (p < 0.05) with a decrease in the particle size compared to the tomato peel powder processed by the CMC method. The crushed tomato powder could enhance the a* and b* values of sausage. Hence, adding varied quantities of tomato peel powder as a more natural food additive to sausages can significantly improve the color of sausage.

With increasing storage time, the NMR spectra of T22 (half-bound water) and T23 (easily flowing water) were significantly reduced in intensity while that of T24 (free water) increased significantly over 48 days of storage. High doses of tomato skin powder reduced the compactness of half-bound water and large molecular substances of sausage and changed half-bound water to free water during sausage storage. After 48-day storage, micrographs demonstrated that the sausage with CMC tomato peel powder showed denser and more compact structures than the formulations containing AUC tomato peel powder. These results also indicated that the sausages with low doses of tomato peel powder were more acceptable to the consumer than that with higher doses of fat substitutes, indicating the potential of tomato peel powder for use as a textural modifier to improve the texture of low-fat sausage.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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