Effects of high-temperature–short time (HTST) drying process on proteolysis, lipid oxidation and sensory attributes of Chinese dry-cured chicken

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ABSTRACT
The objective of this study was to accelerate the drying process of Chinese dry-cured chicken using high temperatures. Salted chicken samples were treated with different high-temperature–short-time (HTST) combinations (50°C/27 h, 55°C/25 h, 60°C/23 h, 65°C/21 h). The effects of various high temperatures on proteolysis, free amino acids (FAAs), thiobarbituric acid reactive substances (TBARS), and sensory attributes were analyzed. The results revealed that high temperature accelerated lipid oxidation, protein oxidation, and proteolysis without producing undesirable flavors. By using the HTST process, the Warner–Bratzler-shear-force (WBSF) values were significantly increased (P < 0.05), and the scores for color, aroma, and taste were enhanced. The best sensory attributes were obtained with the 55°C/25 h treatment. Moreover, samples treated with 55°C/25 h had the highest TBARS values (1.32 mg MDA/kg) and total FAAs contents (4693.2 mg/kg muscle). Therefore, the use of high temperature is an effective way to accelerate the drying process and improve the sensory qualities of Chinese dry-cured chicken.

Efectos del proceso de secado de corto periodo a altas temperaturas (HTST) en la proteólisis, la oxidación lipídica y los atributos sensoriales del pollo curado chino

RESUMEN
El objetivo de este estudio fue acelerar el proceso de secado de pollo curado chino utilizando altas temperaturas. Se trataron muestras saladas de pollo con diferentes combinaciones de periodos cortos a altas temperaturas (HTST) (50°C/27 h, 55°C/25 h, 60°C/23 h, 65°C/21 h). Se analizaron los efectos de diferentes temperaturas altas en la proteólisis, los aminoácidos libres (FAAs), las sustancias reactivas a los ácidos tiobarbitúricos (TBARS) y los atributos sensoriales. Los resultados revelaron que las altas temperaturas habían acelerado la oxidación lipídica, la oxidación proteínica y la proteólisis sin producir sabores indeseables. Mediante la utilización del proceso HTST, los valores de la fuerza cortante de Warner Bratzler (WBSF) (P < 0.05) aumentaron significativamente y se mejoraron los resultados del color, el aroma y el sabor. Los mejores atributos sensoriales se obtuvieron con las muestras tratadas a 55°C/25 h. Además, las muestras tratadas a 55°C/25 h obtuvieron los mayores valores de TBARS (1,32 mg MDA/kg) y de contenido total de FAAs (4693,2 mg/kg de músculo). Por lo tanto, el uso de altas temperaturas es un método efectivo para acelerar el proceso de curado y mejorar las cualidades sensoriales del pollo curado chino.

Introduction
Dry-cured chicken is a traditional dry-cured meat product made in southeast China and is famous for its unique cured flavor. The traditional method for making dry-cured chicken involves natural maturation, which is climate limited and time consuming. Increasing the drying temperature is a potential way of shortening the process of producing dry-cured meat products (Arnau, Serra, Comaposada, Gou, & Garriga, 2007) and has been successfully applied to shorten the drying period of Jinhua ham (J. Zhang, Jin, Wang, & Zhang, 2011). The Chinese sausage industry has also widely used high-temperature dehydration procedures (50–55°C) to accelerate the process (Feng et al., 2014; Sun, Cui, Zhao, Zhao, & Yang, 2011; L. Zhang, Lin, Leng, Huang, & Zhou, 2013). However, increasing the temperature may significantly influence the chemical and biochemical reactions during the drying period, leading to changes in the sensory attributes or deterioration of the finished products. Thus, understanding the effect of high temperature on the physical and chemical characteristics of the product is significant for manufacturers to improve the profit margin and food qualities of Chinese dry-cured chicken.

During the drying period, muscle proteins and lipids are hydrolyzed mainly by endogenous enzymes, resulting in increased amounts of peptides, free amino acids (FAAs), and free fatty acids (Toldrá, Flores, & Sanz, 1997). These products constitute the main characteristics of dry-cured flavor substances and may continue to react with one another or be hydrolyzed to produce volatiles that can contribute to the unique aroma of the final product.
The effect of temperature during the drying period has been described in previous studies (Gou, Morales, Serra, Guàrdia, & Arnau, 2008; Rubio-Celorio, Garcia-Gil, Gou, Arnau, & Fulladosa, 2015; Sánchez-Molinero & Arnau, 2014). Indeed, temperature is an essential factor because it affects the action of endogenous muscle peptidases, which plays an important role in proteolysis (Mora et al., 2015). Martin et al. (1998) observed that the drying temperature determines the levels and the types of compounds released via protein breakdown during the dry curing of Iberian hams. These changes in protein composition contribute to the texture and to the sensory and nutritional quality of meat products (Vissessanguan, Benjakul, Riebroy, & Thepkasikul, 2004). However, high temperature is an important factor for accelerating lipid oxidation, which also exerts effects on the taste and odor compound formation and is also the main reason for off-flavor, rancidity, or textural modification of dry-cured meat products (Broncano, Petrón, Parra, & Timón, 2009; Harkouss et al., 2015). The positive effect of high-temperature ripening on lipolysis and lipid oxidation of Jinhua ham has previously been reported (J. Zhang et al., 2011). However, to the best of our knowledge, few studies have investigated the use of the HTST process for producing dry-cured chicken or its effects on the product’s proteolysis and sensory qualities.

In this study, the HTST drying process was studied as an alternative method to accelerate the process of Chinese dry-cured chicken. The purpose of this work was to study the influence of HTST on the proteolysis, lipid oxidation, and sensory attributes of dry-cured chicken, compared with the traditional drying method to determine the feasibility of using high temperature to reduce the production time of Chinese dry-cured chicken, and to optimize the process parameters.

**Materials and methods**

**Materials**

Chinese native three-yellow-chickens were uniformly slaughtered according to the Animal Experimental Special Committee of Nanjing Agricultural University (NAU), which governs the use of experimental animals. Twenty chicken breasts were collected and subjected to trimming, cleaning, and freezing at −20°C prior to use.

**Dry-cured chicken preparation and sampling**

After thawing at 0 ~ 4°C for 8 h, the chicken breasts were immersed in precooled curing water at 0 ~ 4°C for 20 h (curing formulation: 300 g of salt in 3 kg of water). The salted breasts were hung in a preheated oven (KBF 115-pgm, Binder, Germany). Control samples were treated with one of the traditional methods used by a local factory: drying for 7 days at 15°C with 70% relative humidity. HTST-treated samples were treated with various temperature–time combinations to achieve the same moisture content with the control: 50°C/27 h, 55°C/25 h, 60°C/23 h, and 65°C/21 h (RH = 70%). Immediately after the drying process, the samples were cooled to room temperature for 1 h and vacuum-packaged (DC-800, Promarks Inc., USA) with plastic vacuum packaging bags. Four samples from each treatment were randomly selected for the evaluation of the moisture content and water activity. Eight samples from each treatment were randomly selected and kept at 4°C, of which four were used for the Warner–Bratzler shear force (WBSF) analysis and four were used for the sensory evaluation. All of the WBSF and sensory evaluations were performed the day after the samples were produced. Four samples from each treatment were randomly selected for the analysis of their chemical properties. The remaining samples were kept at −20°C for further use. The entire production procedure was replicated three times at different time points.

**Determination of moisture content and water activity**

Moisture content was determined according to the method specified in ISO-1442 (1997). The samples were dehydrated in an oven (DHG-9033BS-III, Shanghai CIMO Medical Instrument Manufacturing Co., I.TD, Shanghai, China) at 105°C to a constant weight. Water activity ($a_w$) was detected at 25°C using a water activity meter (LabMaster-aw, Novasina AG, Switzerland).

**Instrumental texture analysis**

Tenderness was evaluated via WBSF analysis according to Jose M. Lorenzo, Bermúdez, et al. (2015) with slight modifications. The samples were placed in vacuum bags (unsealed) and heated to 70°C in a water bath (72°C). After being chilled at 4°C for 8 h, four 25 mm × 10 mm × 10 mm (height × width × length) cores were removed from each sample parallel to the muscle fiber direction. Each core was cut vertically in the direction of the muscle fibers using a Warner–Bratzler shear blade. The WBSF data were obtained using a texture analyzer (TA-XTplus, Stable Microsystems, UK).

**Determination of thiobarbituric acid-reactive substances (TBARS)**

The thiobarbituric acid-reactive substances (TBARS) concentration was determined according to Salih, Smith, Price, and Dawson (1987) with slight modifications. A 5 g minced sample was homogenized with 25 mL of cold (4°C) extraction solution containing 20% perchloric acid and 20 mL of distilled water and 0.50 mL of butylated hydroxytoluene (BHT) in a Virtis homogenizer at 10,000 rpm for 1 min. The homogenate was centrifuged at 2000 g for 10 min at 4°C. The blended sample was filtered into a 50-mL Erlenmeyer flask. The filtrate was adjusted to 50 mL with distilled water, and 2 mL of the filtrate was added to 2 mL of 0.02 M TBA. Test tubes were heated in a thermostatically controlled water bath for 30 min at 95°C to develop the malonaldehyde–TBA complex and then cooled for 5 min with cold tap water. The absorbance was determined at 532 nm using a multifunctional microplate reader (Model Spectral Max M2e, MD, USA) against a blank containing 2 mL of 10% per-chloric acid and 2 mL of 0.02 M TBA reagent. The TBARS concentration was calculated from a standard curve in triplicate using solutions of 1,1,3,3-tetraethoxypropane (TEP). The results were expressed as mg malonaldehyde (MDA) equivalents per kg of meat sample.
Protein carbonyls

Protein carbonyl content was evaluated according to the method described by L. Zhang et al. (2013). Carbonyl groups were reacted with 2,4-dinitrophenylhydrazine (DNPH) to develop the protein hydrazones, which were detected by measuring the absorbance at 370 nm in a spectrophotometer (UV-2450, SHIMADZU, Japan). Protein concentrations were calculated using a standard BSA assay by measuring the absorbance at 280 nm. The content of carbonyl groups was expressed as nmol carbonyl/mg protein using an extinction coefficient of 21.0 mM⁻¹ cm⁻¹.

Proteolysis

The protein composition was fractionated according to the method described by Sun et al. (2011) with slight modifications. First, 5 g minced samples were homogenized with 50 mL of phosphate buffer A (15.6 mM Na₂HPO₄ and 3.5 mM KH₂PO₄, pH 7.5) at 8000 rpm for 1 min in an ice bath. The homogenate was centrifuged at 5000 g for 15 min at 4°C. The extraction was repeated twice. The supernatants, which contained water-soluble proteins, were combined. Then the remaining pellet was homogenized with 50 mL of phosphate buffer B (0.45 M KCl, 15.6 mM Na₂HPO₄ and 3.5 mM KH₂PO₄, pH 7.5) at 8000 rpm for 1 min in an ice bath and centrifuged at 5000 g for 15 min at 4°C. The extraction with phosphate buffer B was repeated twice, and the supernatant was combined to obtain salt-soluble proteins.

The concentrations of water-soluble and salt-soluble proteins were determined with a BCA Protein Assay Kit (Pierce, USA). The samples were then mixed with treatment buffer (125 mmol/L Tris, 40 g/L sodium dodecyl sulfate (SDS), and 250 g/L glycerol), heated at 50°C for 20 min and then stored at −80°C for subsequent sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) according to the method described by Etlinger, Zak, and Fischman (1976). The gels were scanned with a GT-800F scanner (EPSON), and then, the densities of the targeted bands were analyzed by Quantity One software (Bio-Rad).

Free amino acids

Free amino acids (FAAs) were analyzed according to the procedures described by Aro et al. (2010).

Sensory evaluation

Sensory evaluation was performed by an experienced sensory panel, composed of 17 members of the National Centre of Meat Quality and Safety Control. The samples subjected to each treatment were cooked in boiling water for 30 min, and then cooled to room temperature. The chicken breasts were then sliced into pieces with thick nesses of approximately 5 mm, and placed on separate white ceramic plates. Each treatment was identified with a random three-digit code. The panelists were instructed to gargle between evaluations to reduce any effects of other samples. All of the tasting sessions were conducted at the same time of each test day in a quiet room with a mixture of natural and fluorescent light, and with no interactions between panelists. Each panelist was asked to evaluate the sensory attributes of the chicken samples of all five treatments, including the color, aroma, taste, and texture. A 9-point hedonic scale was applied (Lim, 2011): 1, dislike extremely; 2, dislike very much; 3, dislike moderately; 4, dislike slightly; 5, neither like nor dislike; 6, like slightly; 7, like moderately; 8, like very much and 9, like extremely.

Results and discussion

Moisture content and water activity (aₘ) analysis

Increasing the temperature did not significantly affect (P > 0.05) the moisture content or aₘ of the dry-cured chicken (Table 1). Moisture is an important factor in the standardization of the product, and it not only affects the final appearance and juiciness but also has great economic importance to the industry. Generally, higher temperature increases the effective water diffusivity and facilitates the migration of water (Sánchez-Moliner & Arnau, 2014). Therefore, the drying-time of each HTST group was adjusted to standardize the moisture of the samples to the control.

Table 1. Moisture content, water activity (aₘ), and WBSF values of Chinese dry-cured chicken treated with various methods.

| Parameter     | Control | 15LT | 50HT | 55HT | 60HT | 65HT | SEM |
|---------------|---------|------|------|------|------|------|-----|
| Moisture (%)  | 59.60 ± 0.73 | 61.18 ± 0.95 | 60.12 ± 0.6 | 60.56 ± 1.12 | 59.68 ± 0.55 | 0.67 |
| aₘ            | 0.89 ± 0.03 | 0.89 ± 0.04 | 0.90 ± 0.02 | 0.91 ± 0.02 | 0.89 ± 0.005 | 0.02 |
| WBSF (kg)     | 2.61 ± 0.14 | 2.26 ± 0.12 | 2.37 ± 0.14 | 2.67 ± 0.11 | 2.98 ± 0.26 | 0.13 |

HTST Treatment: High-temperature–short-time drying treatment.
15LT: 15°C/7 d (control); 50HT: 50°C/27 h HTST treatment; 55HT: 55°C/25 h HTST treatment; 60HT: 60°C/23 h HTST treatment; 65HT: 65°C/21 h HTST treatment.
Means in the same row with different superscripts show significant difference between treatments at P < 0.05.

Statistical analysis

The entire experiment was replicated three times at different times, and a completely randomized design was used. All of the data from the three replicates were analyzed using Excel 2007 (Microsoft, Washington) and SPSS software (SPSS Inc., Chicago, IL, USA). Differences among individual means were compared by Duncan’s multiple range test. Effects were considered significant at P < 0.05.

Sensory evaluation

Sensory evaluation was performed by an experienced sensory panel, composed of 17 members of the National Centre of Meat Quality and Safety Control. The samples subjected to each treatment were cooked in boiling water for 30 min, and then cooled to room temperature. The chicken breasts were then sliced into pieces with thick nesses of approximately 5 mm, and placed on separate white ceramic plates. Each treatment was identified with a random three-digit code. The panelists were instructed to gargle between evaluations to reduce any effects of other samples. All of the tasting sessions were conducted at the same time of each test day in a quiet room with a mixture of natural and fluorescent light, and with no interactions between panelists. Each panelist was asked to evaluate the sensory attributes of the chicken samples of all five treatments, including the color, aroma, taste, and texture. A 9-point hedonic scale was applied (Lim, 2011): 1, dislike extremely; 2, dislike very much; 3, dislike moderately; 4, dislike slightly; 5, neither like nor dislike; 6, like slightly; 7, like moderately; 8, like very much and 9, like extremely.

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Sensory evaluation

Sensory evaluation was performed by an experienced sensory panel, composed of 17 members of the National Centre of Meat Quality and Safety Control. The samples subjected to each treatment were cooked in boiling water for 30 min, and then cooled to room temperature. The chicken breasts were then sliced into pieces with thick nesses of approximately 5 mm, and placed on separate white ceramic plates. Each treatment was identified with a random three-digit code. The panelists were instructed to gargle between evaluations to reduce any effects of other samples. All of the tasting sessions were conducted at the same time of each test day in a quiet room with a mixture of natural and fluorescent light, and with no interactions between panelists. Each panelist was asked to evaluate the sensory attributes of the chicken samples of all five treatments, including the color, aroma, taste, and texture. A 9-point hedonic scale was applied (Lim, 2011): 1, dislike extremely; 2, dislike very much; 3, dislike moderately; 4, dislike slightly; 5, neither like nor dislike; 6, like slightly; 7, like moderately; 8, like very much and 9, like extremely.
The value of $\alpha_w$ indicates the unbound and free water that is available to support the chemical and biological reactions in a system, especially the growth of microorganisms (Feng et al., 2014). No significant differences were found between the $\alpha_w$ values, indicating that HTST did not decrease the storage properties of the dry-cured chicken. This finding was consistent with previously reported results for dry-cured hams (Costa-Corredor, Serra, Arnau, & Gou, 2009).

Tenderness determined by WBSF

Elevating the drying-temperature significantly increased ($P < 0.05$) the WBSF values in the HTST-treated samples (Table 1). The WBSF values of the control group were significantly higher than 50HT ($P < 0.05$) but significantly lower than 65HT ($P < 0.05$), and there was no significant difference between the control and 55HT ~ 60HT ($P > 0.05$). WBSF is related to the tenderness, which is one of the most important sensory characteristics of meat product (Cai, Chen, Wan, & Zhao, 2011). Huang, Huang, Xu, and Zhou (2011) observed a decrease in tenderness when the temperature was increased from 40°C to 60°C, which was consistent with our study. Increased temperature may strengthen the myofibrillar protein networks or cause protein denaturation, leading to toughness (Bouton, Harris, & Shorthose, 1982). However, an appropriate high temperature may also contribute to tenderness by solubilizing the collagen and connective tissue (Bouton et al., 1982), which may explain the lower WBSF value in 50HT. Moreover, Christensen, Purslow, and Larsen (2000) observed an increase in tenderness for the same temperature interval and attributed it to collagen solubility, which was not consistent with our results. This was most likely because of the relatively low collagen content in the longissimus dorsi of chicken breast. Excessive tenderness or toughness may have a negative effect on the texture of the final product (Ishiwatari, Fukuoka, & Sakai, 2013). The relationship between the WBSF values and the texture of Chinese dry-cured chicken was analyzed in the following sensory evaluation.

Lipid oxidation determined by TBARS

Higher drying temperatures significantly influenced ($P < 0.05$) the TBARS values of dry-cured chicken (Table 2). The results showed that the TBARS values increased between 50HT and 55HT, and then gradually decreased between 55HT and 65HT. Yun, Shahidi, Rubin, and Diosady (1987) reported that the lipid-oxidation depends on the thermal-processing temperature. Therefore, the initial increasing phase may be caused by the higher temperature, which was consistent with other studies (Broncano et al., 2009; Wang et al., 2013; Wenjiao, Yongkui, Yunchuan, Junxiu, & Yuwen, 2014). However, aldehydes are unstable and can be directly degraded into volatile compounds (Ventanas, Estévez, Delgado, & Ruiz, 2007), or interact with other groups of proteins (Jin et al., 2012), leading to the formation of fluorescent Schiff bases (Harkous et al., 2015). The formation of such products prevents the reaction of aldehydes and TBA, explaining the subsequent decrease from 55HT to 65HT observed in our study. A similar decrease in TBARS was previously reported by Roldan, Antequera, Armenteros, and Ruiz (2014) in lambs. Several reports showed that lipid oxidation played an important role in the development of the typical dry-cured flavor (Barbieri et al., 1992; Ruiz, Garcia, Muriel, Andrés, & Ventanas, 2002). There was no significant difference between the control group and 55HT and 65HT ($P > 0.05$), indicating that HTST could achieve the same or even higher levels of lipid oxidation. However, excessive lipid oxidation may result in off-flavor in dry-cured meat products (Böttcher, Steinhäuser, & Drusch, 2015). In our study, the TBARS was 0.92–1.32 mg MDA/kg sample, which was higher than the values obtained by Feng et al. (2014) in Chinese sausage and by Cilla, Martínez, Beltrán, and Roncalés (2006) in dry-cured ham, but was lower than the threshold value for off-flavor (2 mg MDA/kg) reported by Wenjiao et al. (2014). The relationship between TBARS and the flavor of dry-cured chicken is further analyzed in the following sensory evaluation.

Protein oxidation determined by protein carbonyl

The results of the HTST groups were significantly higher ($P < 0.05$) than those of the control (Table 2), but increasing the temperature from 50HT to 65HT produced no significant effect ($P > 0.05$). Roldan et al. (2014) reported that protein carbonyls reached similar final values regardless of the heating temperature, which was consistent with our study. Moreover, the higher results in the HTST groups demonstrated the accelerating effect of high temperature on the protein-oxidation rate, which was consistent with a previous study on lamb loins that were heated for 24 h at temperature ranging from 60 to 80°C (Roldan et al., 2014). High temperature is known to enhance protein carbonylation because of several effects, such as the release of free catalytic iron and the formation and cleavage of hydroperoxides (Estévez, 2011). Protein oxidation during the ripening of

### Table 1

| Parameter          | 15LT | 50HT | 55HT | 60HT | 65HT | SEM
|--------------------|------|------|------|------|------|------
| TBARS (mg MDA/kg)  |      |      |      |      |      |      
| Protein carbonyls  |      |      |      |      |      |      

### Table 2

| Parameter          | Control       | HTST Treatment |
|--------------------|---------------|----------------|
| TBARS value        | 0.96 ± 1.01$^{bc}$ | 1.12 ± 0.02$^{bc}$ |
| Protein carbonyls  | 3.70 ± 0.14$^a$ | 4.40 ± 0.27$^{bc}$ |

HTST Treatment: High-temperature—short-time drying treatment. 15LT: 15°C/7 d control; 50HT: 50°C/27 h HTST treatment; 55HT: 55°C/25 h HTST treatment; 60HT: 60°C/23 h HTST treatment; 65HT: 65°C/21 h HTST treatment. Means in the same row with different superindices show significant difference between treatments at $P < 0.05$.

$^a$ Standard error of the mean within the same row.

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$a$ Standard error of the mean within the same row.
meat products was also suggested to be involved in the formation of Strecker aldehydes, which contribute to the dry-cured flavor (Toldrá, 1998). The protein-oxidation results detected here exceeded those recorded for Chinese-style sausage dried at 55°C for 48 h (L. Zhang et al., 2013). This may be due to the different oxidative stabilities of the varying compositions of protein and resistance of muscle fibers to thermal treatment (Ma, Ledward, Zamri, Frazier, & Zhou, 2007). Indeed, the formation of protein carbonyls from particular amino acid side chains contributes to the impairment of the myofibrillar protein conformation (Estévez, 2011).

Proteolysis
Electrophoretic analysis of water-soluble protein (Figure 1A and Table 3) and salt-soluble protein (Figure 1B and Table 4) revealed a significant difference (P < 0.05) between the HTST groups and the control. Water-soluble protein bands with molecular weights of 110 ~ 230 kDa and 35 ~ 50 kDa decreased in the HTST groups, whereas those with a molecular weight of 58 kDa displayed a higher density in 50HT and 55HT but a decreased density in 60HT and 65HT. In addition, those with a smaller molecular weight of 16 ~ 17 kDa increased slightly as the temperature increased. In summary, the HTST process contributes to the degradation of water-soluble proteins with high molecular weights, whereas proteins with smaller molecular weights persisted in 50HT and 55HT.

Salt-soluble proteins had greater thermal stability than water-soluble proteins (Figure 1B). Protein bands with a high molecular weight of 55 kDa ~ 230 kDa gradually decreased from 50HT to 65HT. Bands at 43 ~ 44 kDa and 35 kDa displayed higher densities in 55HT, whereas those at 18 ~ 20 kDa increased slightly as the temperature increased in the HTST groups, which is consistent with the water-soluble protein results.

Proteolysis has an important effect on texture, taste, and, indirectly, the aroma development of dry-cured meat products (Toldrá, 1998). Harkouss, Safa, Gatellier, Lebert, and Mirade (2014) reported that the rates of proteolysis are increased by 3 or 4 times when the temperature is increased. In this study, high temperature resulted in the degradation of proteins with high molecular weights, which was consistent with previous research on Chinese sausage under similar drying conditions (Feng et al., 2014). The results demonstrated the positive effect of high temperature on proteolysis, which is related to the strong activity of muscle proteases in a certain temperature range (50–55°C) (Flores et al., 2006). The additional protease activity caused by high temperature may induce two phenomena: 1. both water-soluble and salt-soluble proteins with high molecular weights are degraded, and 2. more native stromal proteins were most likely hydrolyzed into smaller peptides (Molina & Toldrá, 1992) and FAAs that can directly contribute to the flavor of dry-cured meat products (Cordoba et al., 1994).

FAA content
Total FAA content was significantly (P < 0.05) affected by varying the temperature (Table 5). Samples treated with 55HT had a significantly (P < 0.05) higher total FAA content (4692.7 mg/kg muscle) and a higher concentration of each individual amino acid, except for tyrosine and taurine, which showed higher content in 50HT. In addition, total FAA content in 65HT was significantly (P < 0.05) lower than in other groups. These differences were most likely attributable to the different activities of the proteolytic enzymes at different temperatures. The results of this study were generally lower than those reported in dry-cured ham (Martín, Antequera, Ventanas, Benitez-Donoso, & Córdoba, 2001; Virgili, Saccani, Gabba, Tanzi, & Soresi Bordini, 2007), and Iacón (Lorenzo, Fonseca, Gómez, & Domínguez, 2015). The conversion of peptides into FAAs would occur during the last step of the proteolytic process involved in ripening, mainly produced by cathepsin, calpains, and amino-peptidases (Toldrá et al., 1997). The activities of these enzymes are dependent on the temperature during the drying process (Toldrá et al., 1997; Zhao et al., 2005). Martin et al. (2001) observed that the drying-temperature stimulated proteolytic activity of cathepsin D and exopeptidases of both muscle and microbial origin in Iberian ham, leading to the release of amino acids. Moreover, Zhao et al. (2005) reported that the
Table 3. Relative values of water-soluble protein bands of Chinese dry-cured chicken treated with various methods.  

| Protein bands | Control | HTST Treatment |
|---------------|---------|----------------|
| 230 kDa       | 0.55 ± 0.06<sup>a</sup> | 0.17 ± 0.023<sup>*b</sup> |
| 150 kDa       | 1.17 ± 0.094<sup>b</sup> | 0.16 ± 0.022<sup>*b</sup> |
| 110 kDa       | 1.05 ± 0.051<sup>b</sup> | 0.17 ± 0.033<sup>*c</sup> |
| 58 kDa        | 2.02 ± 0.112<sup>c</sup> | 2.46 ± 0.138<sup>c</sup> |
| 50 kDa        | 1.59 ± 0.083<sup>d</sup> | 0.31 ± 0.031<sup>*a</sup> |
| 44 kDa        | 0.94 ± 0.038<sup>d</sup> | 0.28 ± 0.014<sup>*a</sup> |
| 40 kDa        | 0.42 ± 0.013<sup>e</sup> | 0.11 ± 0.019<sup>*c</sup> |
| 32 kDa        | 3.48 ± 0.213<sup>d</sup> | 2.45 ± 0.161<sup>c</sup> |
| 28 kDa        | 1.02 ± 0.025<sup>f</sup> | 1.81 ± 0.095<sup>c</sup> |
| 18 kDa        | 0.29 ± 0.035<sup>f</sup> | 0.14 ± 0.020<sup>*f</sup> |
| 16 kDa        | 0.39 ± 0.024<sup>f</sup> | 0.43 ± 0.033<sup>c</sup> |

The relative value of protein bands was calculated as the density of targeted bands in different treatment conditions over the density of a reference band of 250 kDa in the marker to avoid the errors between different repetitions.

HTST Treatment: High-temperature–short-time drying treatment.

Table 4. Relative values of salt-soluble protein bands of Chinese dry-cured chicken treated with various methods.  

| Protein bands | Control | HTST Treatment |
|---------------|---------|----------------|
| 230 kDa       | 0.82 ± 0.057<sup>a</sup> | 0.30 ± 0.047<sup>b</sup> |
| 150 kDa       | 0.71 ± 0.041<sup>c</sup> | 0.35 ± 0.044<sup>c</sup> |
| 110 kDa       | 0.86 ± 0.056<sup>d</sup> | 0.48 ± 0.032<sup>c</sup> |
| 90 kDa        | 0.46 ± 0.022<sup>c</sup> | 0.68 ± 0.022<sup>e</sup> |
| 60 kDa        | 0.60 ± 0.049<sup>f</sup> | 0.22 ± 0.043<sup>c</sup> |
| 54 kDa        | 0.82 ± 0.039<sup>f</sup> | 0.55 ± 0.033<sup>c</sup> |
| 43 kDa        | 1.16 ± 0.052<sup>c</sup> | 0.43 ± 0.030<sup>c</sup> |
| 35 kDa        | 1.67 ± 0.063<sup>ab</sup> | 1.52 ± 0.078<sup>d</sup> |
| 30 kDa        | 0.21 ± 0.027<sup>c</sup> | 0.27 ± 0.031<sup>b</sup> |
| 28 kDa        | 0.16 ± 0.015<sup>c</sup> | 0.17 ± 0.039<sup>c</sup> |
| 20 kDa        | 0.23 ± 0.019<sup>c</sup> | 0.12 ± 0.011<sup>*c</sup> |
| 18 kDa        | 0.15 ± 0.017<sup>c</sup> | 0.19 ± 0.017<sup>*c</sup> |

The relative value of proteins bands was calculated as the density of targeted bands in different treatment conditions over the density of a reference band of 250 kDa in the marker to avoid the errors between different repetitions.

HTST Treatment: High-temperature–short-time drying treatment.

at the end of the drying process, the major FAA was glutamic acid with saltiness; alanine with sweetness; arginine, valine, and histidine with bitterness; tyrosine and lysine with aged taste; and leucine with acid taste (Careri et al., 1993). The combination of all of the FAAs contributes to the characteristic taste of dry-cured ham (Bermúdez, Franco, Carballo, Sentandreu, & Lorenzo, 2014). The higher FAA content in 5HTH might make an important contribution to improving the flavor of dry-cured chicken. Besides, the FAAs may also act as flavor precursors in the generation of
Tabla 5. Aminoácidos libres (mg/kg de músculo) de pollo curado chino tratado con diferentes métodos.

| Aminoácidos | Control | 50HT | 55HT | 60HT | 65HT | SEM * |
|-------------|--------|------|------|------|------|------|
| Asp         | 172.3 ± 11.0 a | 196.3 ± 20.2 b | 235.5 ± 17.1 c | 180.0 ± 1.80 b | 105.3 ± 0.69 b | 12.6 |
| Glu         | 353.8 ± 24.4 a | 397.9 ± 34.5 a | 491.9 ± 11.8 a | 346.6 ± 4.00 a | 254.1 ± 1.13 a | 22.1 |
| Ser         | 273.1 ± 17.6 b | 289.5 ± 10.7 b | 323.7 ± 17.4 b | 265.6 ± 2.48 b | 185.5 ± 0.72 b | 13.6 |
| Gly         | 146.8 ± 8.3 c  | 207.1 ± 13.8 d | 248.2 ± 17.0 d | 174.8 ± 1.22 c | 115.1 ± 0.53 c | 9.8  |
| His         | 158.7 ± 14.8 c | 166.2 ± 9.6 bc | 187.1 ± 16.0 b | 151.8 ± 1.67 np | 94.5 ± 0.25 np | 10.7 |
| Tau         | 83.8 ± 9.0 c   | 63.8 ± 5.2 a  | 58.2 ± 6.5 a   | 53.8 ± 0.39 a  | 71.4 ± 0.29 a  | 4.8  |
| Arg         | 296.1 ± 17.4 c | 322.3 ± 24.3 b | 329.7 ± 24.3 b | 280.4 ± 3.22 b | 227.2 ± 1.31 b | 19.0 |
| Thr         | 192.6 ± 11.2 c | 226.6 ± 6.7 d | 293.3 ± 8.1 d  | 200.4 ± 1.88 b | 149.2 ± 1.03 b | 9.6  |
| Ala         | 372.4 ± 15.8 b | 436.0 ± 24.2 c | 497.3 ± 27.6 c | 381.3 ± 3.61 b | 270.6 ± 1.65 b | 20.6 |
| Tyr         | 205.8 ± 3.1 c  | 270.1 ± 4.6 b  | 217.2 ± 16.7 b | 222.0 ± 2.27 b | 201.2 ± 1.10 b | 11.2 |
| Val         | 216.8 ± 15.4 b | 247.7 ± 3.8 c  | 284.9 ± 9.3 c  | 217.0 ± 1.8 c  | 176.4 ± 1.04 c | 10.2 |
| Met         | 142.3 ± 1.9 a  | 172.3 ± 2.9 a  | 187.5 ± 7.8 a  | 151.0 ± 1.50 a | 117.9 ± 0.51 a | 6.6  |
| Ile         | 178.4 ± 14.4 b | 203.3 ± 4.4 d  | 242.8 ± 8.0 d  | 186.6 ± 1.10 c | 159.5 ± 0.64 c | 7.8  |
| Leu         | 330.7 ± 14.9 a | 383.6 ± 15.1 c | 404.8 ± 32.1 c | 340.2 ± 1.65 b | 281.2 ± 1.33 a | 16.0 |
| Phe         | 194.0 ± 18.7 a | 270.4 ± 18.4 ad | 302.3 ± 13.8 ad | 256.4 ± 2.60 ac | 226.0 ± 0.96 ab | 14.9 |
| Lys         | 366.1 ± 27.2 b | 395.5 ± 29.4 b | 426.7 ± 20.4 b | 385.4 ± 3.50 b | 253.5 ± 0.33 c | 20.8 |
| Total       | 1868.5 ± 225.4 a | 4286.9 ± 218.5 b | 4692.7 ± 262.7 d | 3793.3 ± 347.3 b | 2888.4 ± 135.3 c | 151.8 |

HTST Treatment: High-temperature short-time drying treatment.
15LT: 15°C/7 d control; 50HT: 50°C/27 h HTST treatment; 55HT: 55°C/25 h HTST treatment; 60HT: 60°C/23 h HTST treatment; 65HT: 65°C/21 h HTST treatment.

A Standard error of the mean within the same row.

Sensory evaluation

No undesirable flavors or tastes were observed by the panelists in the sensory evaluation of the samples (Table 6). For the color scores, a significant difference (P < 0.05) was found between the HTST groups and the control. The samples in the HTST groups were significantly more appreciated by the panelists for their light and fresh colors. Samples treated with 50HT, 55HT, and 60HT showed significantly higher scores for aroma (P < 0.05) than 65HT and the control. In addition, the 50HT and 55HT groups showed higher scores for taste. Thus, as the drying-temperature increased, the scores of color, aroma, and taste followed the similar trend. The highest score for texture was observed in 55HT and 60HT, whereas excessive toughness was indicated by lower texture scores in 65HT.

The sensory quality of the dry-cured meat product was affected by the biochemical reactions during the drying process. The scores revealed a significant effect of high temperature on color, aroma, taste, and texture, which may result from the accelerated lipid oxidation and additional proteolysis. Color is an important trait in food quality and is considered to be an indicator of meat freshness and doneness for consumers (Hung et al., 2011). The results showed that samples treated with the HTST process obtained a higher color score because of an impression of brightness. An increase in brightness was also found in the study of dry-cured ham treated with the HTST process (Sánchez-Molineró & Arnau, 2014). For the aroma and taste scores, many researchers have reported that a variety of small peptides and FAAs produced by the dry-cured meat products contribute to aroma characteristics (Virgili et al., 2007), taste properties, and water-soluble flavor precursors (Koutsidis et al., 2008). In addition, Careri et al. (1993) found

Tabla 6. Sensory attributes of Chinese dry-cured chicken treated with various methods.

| Atributos sensoriales | Control | 50HT | 55HT | 60HT | 65HT | SEM a |
|-----------------------|--------|------|------|------|------|------|
| Color                 | 6.21 ± 0.09 a | 7.63 ± 0.19 bc | 7.82 ± 0.06 c | 7.78 ± 0.09 b | 7.45 ± 0.12 b | 0.16 |
| Aroma                 | 5.94 ± 0.24 a | 7.06 ± 0.12 a | 7.22 ± 0.03 c | 7.04 ± 0.19 b | 6.75 ± 0.09 b | 0.13 |
| Taste                 | 6.4 ± 0.25 b | 7.22 ± 0.23 bc | 7.49 ± 0.19 c | 7.21 ± 0.18 bc | 6.87 ± 0.45 bc | 0.12 |
| Texture               | 6.94 ± 0.18 a | 7.92 ± 0.38 b | 7.35 ± 0.16 d | 7.27 ± 0.12 d | 5.24 ± 0.06 a | 0.22 |

HTST Treatment: High-temperature short-time drying treatment.
15LT: 15°C/7 d control; 50HT: 50°C/27 h HTST treatment; 55HT: 55°C/25 h HTST treatment; 60HT: 60°C/23 h HTST treatment; 65HT: 65°C/21 h HTST treatment.

a Standard error of the mean within the same row.
that hams with the highest acceptability scores had high levels of free tyrosine and lysine. In our study, samples with a higher FAA content obtained a higher score for taste, which confirmed the correlation between FAAs and the taste of dry-cured meat products. Finally, texture is rated by consumers as the most important quality characteristic of meat (Shackelford et al., 2001). The scores for texture revealed that high temperature made no significant difference between 55HT and 60HT and the control but did result in remarkable toughness, as indicated by the lower texture scores in 65HT. According to the results of sensory evaluation, the best HTST treatment parameters should be 55HT (55°C/25 h).

Conclusion

By decreasing the drying time to less than 25 h, the HTST process effectively accelerated proteolysis, as reflected by the decrease in the large molecule protein bands of both water-soluble and salt-soluble proteins. Tenderness was significantly (P < 0.05) affected by the temperature, as indicated by the increased WBFS. The oxidation of protein and lipids was accelerated by the HTST drying treatment, while no undesirable flavors or tastes were observed in the sensory panel. Samples treated at 55HT (55°C/25 h) exhibited the highest contents of total FAAs and most of the individual FAAs. The color, aroma, and taste scores in the HTST groups were significantly (P < 0.05) higher than in the control. The best sensory attributes were observed in 55°C/25 h-treated samples. In conclusion, applying high-temperature drying condition is a novel method with great potential to accelerate the manufacture of Chinese dry-cured chicken and improve its sensory properties.

Disclosure statement

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