J Food Sci Technol (June 2016) 53(6):2760–2769
DOI 10.1007/s13197-016-2248-2

ORIGINAL ARTICLE

Effect of pre-cooking methods on the chemical and sensory deterioration of ready-to-eat chicken patties during chilled storage and microwave reheating

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Revised: 6 May 2016 / Accepted: 10 May 2016 / Published online: 22 June 2016

Abstract The effects of pre-cooking methods, namely, boiling (BL), roasting (RT) and grilling (GR), refrigerated storage (14 days/+4 °C) and microwave reheating on chicken patties were studied. Physical, chemical and sensory parameters were evaluated in order to correlate the chemical deterioration of ready-to-eat chicken patties with the acceptance of the odor. Chemical deterioration was evaluated through the chemical composition, Maillard compounds, Thiobarbituric acid-reactive substances (TBARS) and volatiles. Sensory deterioration (odor liking) was performed by an acceptance test with hedonic scale. According to the TBARS values and volatile compounds generated in the head space during the examined stages, the pre-cooking method and the storage time had a significant effect on lipid oxidation, whereas reheating in a microwave had a negligible impact. At each succeeding processing stage, panelists gave lower odor scores to all samples and no significant differences were found between treatments at any stage. RT and GR patties showed less intense chemical changes and presented higher acceptation scores by the sensory panel than BL patties. Thus, the choice of pre-cooking method and control of storage conditions plays a key role in the inhibition of oxidative changes in ready-to-eat chicken patties.

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Keywords Convenience food · Pre-cooking · Microwave reheating · Lipid oxidation · Odor

Introduction

Consumers appreciate ready-to-eat (RTE) food items for being (i) a convenience way to save time and effort, (ii) a good alternative to other fast food and (iii) a solution to a growing lack of cooking skills (Olsen et al. 2009). On this line, Europe has witnessed in the last 5 years an increase in the consumption of heat-and-eat and RTE meat and poultry, such as meat balls, burger patties, sausages and other processed muscle foods (Analytics 2014). The market of convenience food in Europe was calculated to have a value of 47 bill euros in 2012, almost 20 % higher than in 2007 (Kanzler and Wagner 2009).

The shift from freshly prepared dishes to processed RTE food may involve a loss of quality in terms of sensory properties and nutritional value. The manufacture of these items typically involves a number of consecutive processing stages, namely, pre-cooking, cold storage and a final reheating step prior to consumption (Kanzler and Wagner 2009). The long and severe technological processes applied to the meat, which includes size reduction, salting, and various heating steps, facilitates the onset of oxidative reactions that affect, in turn, the sensory properties and nutritional value of the final meat product (Pegg and Shahidi 2012; Soladoye et al. 2015). In particular, cooked meats are known to develop a fast and intense flavor deterioration during the subsequent cold storage commonly described as warmed-over-flavor (WOF) (Pegg and Shahidi 2012). This deterioration process is particularly relevant in poultry products owing to their high degree of fat unsaturation and high susceptibility to oxidative reactions (Pegg

and Shahidi 2012). While the onset of lipid oxidation and WOF has been profusely studied in cooked and subsequently refrigerated meat in terms of influential factors (Byrne et al. 2001a, b), methodological approach (Brøndum et al. 2000; Sullivan et al. 2003) and sensory characterization of WOF (Byrne et al. 1999), the evolution of lipid oxidation and key-odorants during the whole processing (including the final heating stage) requires an in-depth consideration. Some studies have examined the effect of assorted cooking procedures (frying, boiling, roasting, among others) on the chemical composition and quality traits on muscle foods (Estévez et al. 2003; Ramírez et al. 2005; Roldán et al. 2014a, b). The nature of the cooking method determines the mass and energy transfer phenomena, the modification of the meat and hence, the properties of the cooked product (Ramírez et al. 2005; Matsuda et al. 2013; Roldán et al. 2014a, b). However, there is little information in the scientific literature on the impact of the pre-cooking method on the susceptibility of a convenience meat product to suffer further deterioration during the following processing stages (chilled storage and reheating).

Therefore, the aim of the present study was to investigate the effect of assorted pre-cooking methods (boiling, roasting and grilling) on the physico-chemical properties of chicken patties and on their susceptibility to undergo lipid oxidation and odor deterioration during the succeeding processing stages: refrigerated storage and final reheating.

Materials and methods

Chemicals and reagents

All chemicals were supplied from Panreac (Panreac Quimica, S.A., Barcelona, Spain), Merck (Merck, Darmstadt, Germany), Sigma Chemicals (Sigma-Aldrich, Steinheim, Germany) and Scharlau (Gillman, South Australia). Water used was purified by passage through a Milli-Q system (Millipore Corp., Bedford, MA, USA).

Processing of chicken patties

The chicken patties were made with chicken thigh and drumstick (1:1, w/w) obtained from a local market in the city of Cáceres (Spain). A total of 64 chicken patties were prepared in two separate processes following the general basic recipe: 80 % meat, 2 % sodium chloride, and 18 % of cold water. Following the procedure described by Ganhão et al. (2010), emulsified experimental patties were produced to guarantee a homogeneous product. After 6 min of homogenization in cutter (Mainca®, USA) the chicken patties (~100 g) were molded in a burguermarker (10 cm diameter and 1 cm thickness) and submitted to three processes of pre-cooking: boiling (80 °C/30 min) (n = 20); grilling (250 °C/8 min) (n = 20); and roasting (170 °C/16 min) (n = 20). All temperatures refer to internal temperatures measured during cooking in the core of patties using a digital probe thermometer (Testo thermocouple, Mod. 735-1, Lenzkirch, Germany). Raw samples (prior to pre-cooking) were also analyzed in order to characterize the chicken patties. Boiled patties were packed in a plastic bag and immersed in a thermostatized water bath. Grilling was made on an electrical griddle (Repagas, 550 series, Madrid, Spain) while roasting was performed in an electrical oven (Unox®, Mod. GN2.1, Cadonegue, Italy). Each pre-cooking method was also performed twice. One set of pre-cooked patties (n = 4 for each pre-cooking method) was immediately frozen at −80 °C for further analyses. The remaining pre-cooked patties were dispensed in polypropylene trays, wrapped with polyvinyl chloride film (oxygen permeability: ~17 cm^3/m^2 day atm; moisture permeability: <5 g/m^2 day; Tecnodur S.L., Valencia, Spain) and stored at +4 °C for 14 days. Samplings (n = 8 for each pre-cooking method) were performed at days 7 and 14. Half of the patties (n = 4 for each pre-cooking method and sampling time) were frozen at −80 °C for further analyses. The other half of pre-cooked and refrigerated patties (n = 4 for each pre-cooking method and sampling time) were reheated in a microwave (600 mW/1 min; Daewoo, Mod. KOR-6L75; Daewoo Electronics Sales UK Ltd). Upon reheating, samples were also frozen at −80 °C for further analyses.

Analytical methods

Chemical composition and fatty acid profiles

Moisture and total protein were determined using AOAC methods (AOAC 2000). The method of Folch et al. (1957) was used for determining fat content in patties. Fatty acid methyl esters (FAMEs) were prepared by methylation with cold a methanolic solution of potassium hydroxide (Cert et al. 2000). FAMEs were separated using a Hewlett–Packard HP-5890A gas chromatograph, equipped with an on-column injector, a flame ionization detector and a capillary column Supelco® (50 m × 0.32 mm internal diameter, 1.0 μm film). Detector gas flow rates were 35 mL min^{-1} for the hydrogen, 15 mL min^{-1} for the helium and 400 mL min^{-1} for the synthetic air. Helium was used as the carrier gas (flow rate 1.7 mL min^{-1}). The initial column temperature was programed to 180 °C for 5 min, which was then increased to 210 °C at 1 °C min^{-1} and held at the maximum temperature for 30 min. Subsequently, the temperature was increased to 250 °C at 4 °C min^{-1} and held at the maximum temperature for 20 min,

resulting in a total run time of 55 min. The Supelco 37 Component FAME Mix (Sigma-Aldrich, Steinheim, Germany) was used as a reference standard to identify the fatty acid peaks.

Cooking loss

The cooking loss was calculated from differences in the weight of raw (W_R) and cooked samples (W_C) as follows: % Cooking Loss $= ((W_R - W_C)/W_R) \times 100$.

Maillard reaction products (MRPs) quantification

For extraction of colored materials formed by cooking, 0.5 g of each sample was finely ground and placed in a glass tube. A mixture of methanol:water milliq (1:1, v/v) was used for the extraction of colored materials. Tubes were hermetically closed and placed in an orbital shaker. After 1 h, tubes were centrifuged at 5000*g* for 20 min. Pellets were discarded and the absorbances of supernatants were recorded at 420 nm. The molar extinction coefficient (1.00 ± 0.03 l mmol^{-1}cm^{-1}) reported by Martins and Van Boekel (2003) was applied to calculate the concentration of MRPs in our samples.

Thiobarbituric acid-reactive substances (TBARS)

Thiobarbituric acid-reactive substances (TBARS) were extracted in acidic conditions and quantified spectrophotometrically following the method described by Ganhão et al. (2011).

Analysis of volatiles

The odor-active volatiles was analyzed in pre-cooked, chilled and reheated samples by headspace-SPME and GC/MS (gas chromatograph Hewlett–Packard 5890 series II coupled to a mass selective detector Hewlett–Packard HHP-5791A) following the method reported by Estévez et al. (2003). 1 gram of minced sample was weighed into a 4 mL vial. An SPME fibre (50/30 µm divinylbenzene–carboxen–polydimethylsiloxane coating) was inserted through the septum and exposed to the headspace of the vial. The SPME fiber was preconditioned prior analysis at 220 °C during 45 min. Vials were preconditioned for 10 min at 37 °C. Extraction was carried out at 37 °C for 30 min in an oven. After extraction, the SPME fiber was immediately transferred to the injector of the chromatograph which was in splitless mode. The separation of volatile compounds was performed on a 5 % phenylmethyl silicone (HHP-5)-bonded-phase fused-silica capillary column (Hewlett–Packard, 50 m × 0.32 mm i.d., film thickness 1.05 m). The carrier gas was helium at 18.5 psi, resulting in a flow of 1.6 mL min^{-1} at 40 °C. The SPME fiber was desorbed and maintained in the injection port at 220 °C during the whole chromatography run. The temperature program was isothermal for 10 min at 40 °C and then increased at the rate of 7 °C min^{-1} to 250 °C and held for 5 min. The GC–MS transfer line temperature was 270 °C. The mass spectrometer operated in the electron impact mode with an electron energy of 70 eV and a multiplier voltage of 1650 V and collected data at a rate of 1 scan s-1 over a range of *m*/*z* 40–300. Compounds were positively identified by comparing their mass spectra with those from standard compounds (Sigma-Aldrich, Steinheim, Germany). Results are expressed as area units (AU) × 10^6.

Objective color measurement

Color measurements were performed by measuring lightness (L*), redness (a*) and yellowness (b*) values in triplicate at different random points on the surface of the chicken patties using a portable Minolta Chromameter CR-300 (Minolta Co., Ltd, Osaka, Japan) equipped with a measuring head (CR-300). Color measurements were made on patties at ambient temperature (~20 °C) with an illuminant D65 and a 0° angle observer prior to frozen storage at −80 °C. The equipment was previously calibrated with the white tile provided by the supplier.

Odor liking assessment

The odor liking assessment of ready-to-eat chicken patties was performed by 30 untrained panelists (staff and students from the Veterinary Faculty in Caceres, Spain). Panelists were regular consumers of processed muscle foods and ranged in age from 25 to 60. A hedonic scale of seven points from extremely disliked (1) to extremely liked (7) was used. Five grams of each sample were finely minced, dispensed in falcon tubes, sealed and wrapped with aluminum foil and offered to the panelists after being warmed up to 37 °C for 10 min in oven. Each sample was coded with three random numbers.

Statistical analysis

Four ready-to-eat chicken patties per treatment and sampling point were prepared in corresponding replicated processes and used as experimental units. The effect of the technological treatments on each measured parameter was analyzed by one-way analyses of variance (ANOVA) and Tukey's tests. A Kruskal–Wallis analysis was applied to sensory data. A significance level of $p < 0.05$ was considered.

Results and discussion

Impact of pre-cooking method on composition of chicken patties

The chemical composition of the chicken patties is shown in Table 1. After pre-cooking, all treatments had lower moisture values than raw samples owing to the dehydration of samples during the heat treatment. Roasted (RT) samples presented the lowest moisture value (67.66 %), the boiled (BL) treatment led to samples with the highest moisture content (71.33 %) while grilled (GR) samples had intermediate moisture values (68.82 %). Regarding to lipid content, no differences were observed ($p > 0.05$) between BL and raw samples, which had 9.08 and 9.93 %, respectively. However, RT and GR patties had 1.09 and 1.18 times higher lipid contents than raw samples, respectively. These results, as well as the highest protein value in RT samples, may be attributed to a highest loss of water during pre-cooking (Table 1). The fatty acid composition was not influenced by the pre-cooking method ($p > 0.05$). Chemical composition of the present pre-cooked chicken patties is comparable with similar cooked poultry products characterized in previous studies (Conchillo et al. 2005; Mora et al. 2011). Mass and energy transfer processes, which occur differently in each pre-cooking method, can be mainly responsible for the observed behaviors (Adedeji et al. 2009).

Impact of pre-cooking method on cooking loss, Maillard compounds and color of chicken patties

The cooking loss values, color parameters (L*, a* and b*) and Maillard compounds are shown in Table 2. The losses found in RT (17.31 %) and GR samples (13.15 %) were consistent with those observed by Domínguez et al. (2014) who studied the influence of these cooking methods in foal meat. The BL treatment caused the lowest cooking loss (4.51 %), a fact confirmed by Juárez et al. (2010) when analyzing the influence of different cooking methods on buffalo meat. The low values observed for BL treatment may be due to (i) the mild temperatures applied during cooking and (ii) the hindrance of water evaporation during cooking as the samples were packed in plastic bags through which the heat transfer occurred (Kanzler and Wagner 2009).

Regarding the color after cooking, the RT and GR chicken patties were, in general, darker, less red and more yellow than raw samples (Table 2). BL samples, conversely, were as yellow as the raw samples and displayed a

Table 1 General and fatty acid composition (mean ± SD) of chicken patties subjected to different pre-cooking methods

	R	Boiled	Roasted	Grilled	p^a
Moisture[b]	72.78a ± 0.20	71.33b ± 0.65	67.66d ± 0.18	68.82c ± 0.50	<0.001
Protein[b]	14.25c ± 0.33	16.10b ± 0.57	17.33a ± 0.53	16.18b ± 0.54	<0.001
Lipid[b]	9.93bc ± 0.70	9.08c ± 0.46	10.87ab ± 0.60	11.71a ± 0.73	<0.001
Fatty acid profile[c]					
C12	0.06 ± 0.02	0.07 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.794
C14	1.23 ± 0.05	1.19 ± 0.05	1.22 ± 0.07	1.23 ± 0.09	0.797
C16	29.73 ± 0.50	29.04 ± 0.61	29.63 ± 1.58	29.37 ± 2.11	0.893
C16:1	8.76 ± 0.33	8.74 ± 0.45	8.45 ± 0.54	8.78 ± 0.50	0.712
C17	0.14 ± 0.02	0.15 ± 0.01	0.14 ± 0.02	0.15 ± 0.02	0.750
C17:1	0.09 ± 0.03	0.12 ± 0.02	0.12 ± 0.01	0.11 ± 0.01	0.253
C18	5.32 ± 0.14	5.26 ± 0.12	5.35 ± 0.53	5.23 ± 0.48	0.963
C18:1n-9	40.46 ± 1.31	40.33 ± 1.03	40.00 ± 1.89	40.06 ± 2.78	0.983
C18:2n-6	12.36 ± 1.35	13.19 ± 1.44	13.09 ± 1.31	13.10 ± 0.66	0.764
C18:3n-6	0.11 ± 0.01	0.11 ± 0.01	0.11 ± 0.01	0.11 ± 0.01	0.757
C18:3n-3	0.99 ± 0.15	1.07 ± 0.14	1.07 ± 0.14	1.06 ± 0.08	0.779
C20:1	0.26 ± 0.01	0.25 ± 0.02	0.26 ± 0.02	0.26 ± 0.02	0.939
C20:2	0.10 ± 0.02	0.10 ± 0.01	0.11 ± 0.01	0.10 ± 0.02	0.569
C20:4n-6	0.38 ± 0.03	0.38 ± 0.01	0.39 ± 0.04	0.39 ± 0.04	0.964

Different letters denote significant differences ($p < 0.05$) between pre-cooking methods

R Raw patties

[a] Statistical significance in ANOVA

[b] Data expressed as g/100 g sample

[c] Data expressed as percentage of total fatty acids analyzed

Table 2 Cooking loss, instrumental color and Maillard reaction products (MRPs), in chicken patties subjected to different pre-cooking methods

	R	Boiled	Roasted	Grilled	p^a
Cooking loss[b]	–	4.51c ± 0.63	17.31a ± 2.18	13.15b ± 1.91	<0.001
L*	73.03b ± 0.48	74.49a ± 1.24	65.65d ± 1.90	67.61c ± 1.35	<0.001
a*	11.74a ± 0.43	4.34b ± 0.39	4.81b ± 0.93	4.44b ± 0.83	<0.001
b*	11.99c ± 0.30	11.68c ± 0.42	17.90b ± 0.77	22.61a ± 3.70	<0.001
Chroma	16.79b ± 0.41	12.46c ± 0.49	18.55b ± 0.78	23.07a ± 3.62	<0.001
Hue	44.41a ± 1.12	20.37b ± 1.41	15.04c ± 2.82	11.38d ± 2.86	<0.001
MRPs[a]	–	15.91c ± 2.49	30.91b ± 7.69	45.86a ± 10.84	0.001

Different letters denote significant differences ($p < 0.05$) between pre-cooking methods

R Raw patties

[a] Statistical significance in ANOVA

[b] Data expressed as percentage

higher lightness and the lowest chroma among chicken patties, which is consistent with previous findings (Roldán et al. 2014a, b; 2015). Significant differences were also observed for Chroma and Hue, on which a* and b* are dependent. The observed changes in color parameters may be caused by a combination of factors, including (i) the cooking loss and ensuing concentration of other meat components, (ii) the denaturation/oxidation of heme pigments and other meat proteins (Estévez and Cava 2004; Ganhão et al. 2010) and (iii) the formation of various colored products generated from the Maillard reaction (Martins et al. 2000). On this line, pre-cooking methods had a significant impact on the formation of MRPs and this influence may actually contribute to explaining the differences already reported for the instrumental color of the samples. In agreement with the yellowness and chroma of pre-cooked samples, GR chicken patties showed the highest amounts of MRPs followed by RT and BL samples. It is known that the formation of Maillard compounds (mainly melanoidins) is affected by the cooking method and cooking temperature (from 55 to 75 °C to initiate reactions) (Ganhão et al. 2010; Ramírez et al. 2005). Considering that the intensity of the Maillard reaction is proportional to the temperature reached during cooking and that contact–heat transfer (as that occurred during grilling) facilitates the formation of MPRs compared to convention heat transfer (occurred during roasting for instance) (Matsuda et al. 2013) the obtained results are reasonable. The formation of these colored compounds after cooking can be a positive factor for acceptance by the consumer (Aaslyng et al. 2007; Berry 1998)

TBARS of chicken patties during pre-cooking, chilling and reheating

The results for lipid oxidation, analyzed by the formation of TBARs during processing, are showed in Fig. 1. Among pre-cooking methods, BL caused the highest TBARS numbers (0.6 mg MDA/kg sample), which are consistent with those reported by Weber et al. (2008) in fish fillets (0.8 mg MDA/kg sample) subjected to a similar cooking method. In agreement with the present results are also those reported by Conchillo et al. (2005) in grilled (0.2 mg MDA/kg sample) and roasted chicken breast (0.3 MDA/kg sample).

The highest increase in TBARS values occurred in the first 7 days of chilled storage. TBARS increased 4.25, 7.37 and 6.80-fold times in BL, RT and GR samples respectively. Chilling the samples for 7 additional days increased TBARS only 1.14-fold times on average for all treatments. Again, BL samples had significantly higher TBARS at day 7 than samples subjected to the other pre-cooking methods. Reheating in the microwave at either day 7 or day 14 caused no significant increase of TBARS in any of the samples. Satyanarayan and Honikel (1992) reported that the microwave heating may be the main source of lipid oxidation and impaired quality in fish fillets. In this study, conversely, we observed that the chilled storage of pre-cooked samples had more influence on the increase in TBARS values that the final reheating stage. At the chilling stage, the TBARS values exceeded the limit of consumer acceptability that has been established by several authors between 2 and 3 mg MDA/kg, depending on the meat animal and processing technology applied (Campo et al. 2006; Greene and Cumuze 1982). Above this threshold, rancidity may be perceived by consumers.

The differences between the pre-cooking methods can be explained by the influence of time and temperature in addition to other parameters dependent on the cooking method such as the extent of tissue disruption and the nature of chemical reactions occurred during cooking (Weber et al. 2008). The authors hypothesized whether MDA formed during grilling could be lost by decomposition or by complexation with proteins. While higher TBARS would have been expected in sample subjected to a higher cooking temperature, other factors may have also

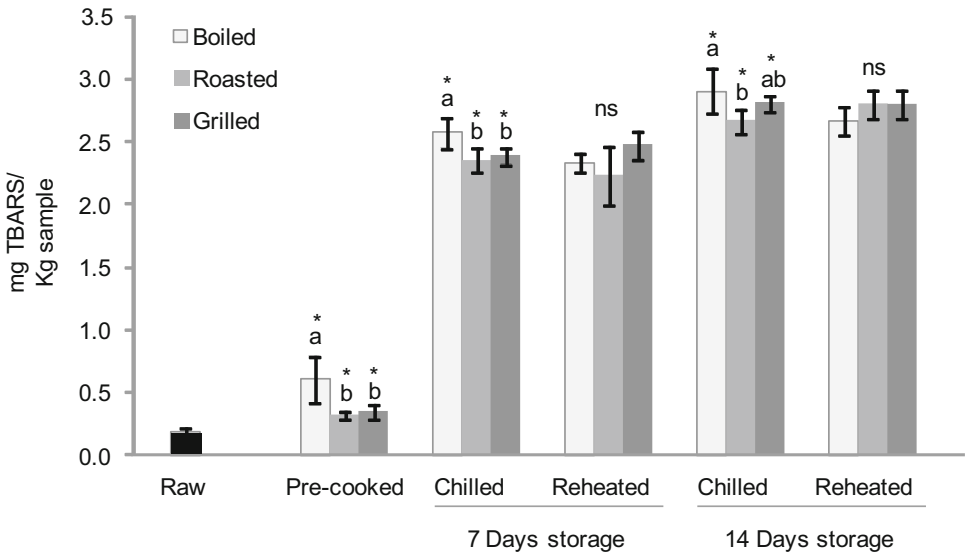

Fig. 1 TBARS (mg MDA/kg sample) of raw, pre-cooked, chilled (for whether 7 or 14 days at +4 °C) and reheated chicken patties. *Different letters* on *top* of *bars* denote significant differences ($p < 0.05$) between pre-cooking methods within a particular processing stage. *ns* No significant differences between pre-cooking methods within a particular processing stage ($p > 0.05$). An *asterisk* on *top* of a *bar* denotes significant differences ($p < 0.05$) between that processing stage and the immediately previous one within a particular pre-cooking method

been influential. For instance, BL for 30 min may have caused a higher disruption of cellular compartmentalization in the whole product, facilitating the exposure of membrane lipids to pro-oxidants (Kristensen and Purslow 2001). The physical damage caused in GR samples is presumably limited to the surface while RT samples were subjected to an intense heat treatment for a shorter period of time. The presence of higher amounts of MRPs in RT and GR samples may have also protected lipids against oxidative damage as these products have been found to exert antioxidant properties in meat systems (Serpen et al. 2012). Regardless of the pre-cooking method, all samples had similar TBARS at the final reheating stage.

Color changes in chicken patties during pre-cooking, chilling and reheating

The changes in color parameters (L, a* and b*) of chicken patties during processing are showed in Fig. 2. The lightness of BL remained unaffected during cold storage and reheating, while RT and GR samples showed significant modifications ($p < 0.05$), except after reheating upon 7 days of storage (Fig. 2a). The redness decreased in all samples during the subsequent chilled storage (Fig. 2b). After the first 7 days of cold storage, pre-cooking methods showed significant differences ($p < 0.05$) and the GR samples showed the highest redness values. The reheating in microwave did not have any influence on redness, nor at day 7 neither at day 14. The changes in yellowness only affected to some patties at particular processing stages and no common trend was observed (Fig. 2c). The loss of redness and the increase of lightness in chicken patties during chilled storage may be possibly related to the oxidative degradation of denatured globin and the oxidative cleavage of hematin pigment which releases iron from heme molecule (Estévez and Cava 2004). These changes have been already reported and interpreted as an undesirable discoloration of cooked meats subjected to chilled storage (Ganhão et al. 2010).

Odor-active volatiles in chicken patties during pre-cooking, chilling and reheating

Among the total volatiles found in the headspace of the chicken patties during pre-cooking, chilling and reheating, selected lipid-derived carbonyls and Maillard-derived compounds were analyzed (Fig. 3). The carbonyls, namely, hept-(*E*)-enal, Oct-(*E*)-enal, deca-2,4-di-(*EE*)-enal, heptan-2-one, octan-2-one, 3-hydroxy-butan-2-one and octane-2,3-dione (Fig. 3a) have been highlighted by many previous authors as reliable indicators of the oxidative damage to muscle lipids (Estévez et al. 2003; Konopka et al. 1995; Madruga et al. 2009; Roldán et al. 2014a, b). In general, each stage led to a significant increase of this group of volatile compounds in the headspace of the chicken patties, reflecting that lipids suffered successive oxidative degradation during processing. With the exception of reheated samples after 7 days of chilled storage, BL samples had significantly higher amount of lipid-derived volatiles than samples subjected to the other two pre-cooking methods during the subsequent chilling and reheating stages. The more intense lipid oxidation in BL samples reflected in the TBARS values, is now confirmed by the analysis of lipid-derived volatiles.

The increase of particular lipid-derived volatiles during refrigerated storage of pre-cooked meats has been related to the onset of undesirable odors typically described Warmed-Over Flavor (WOF). This hypothesis was in fact

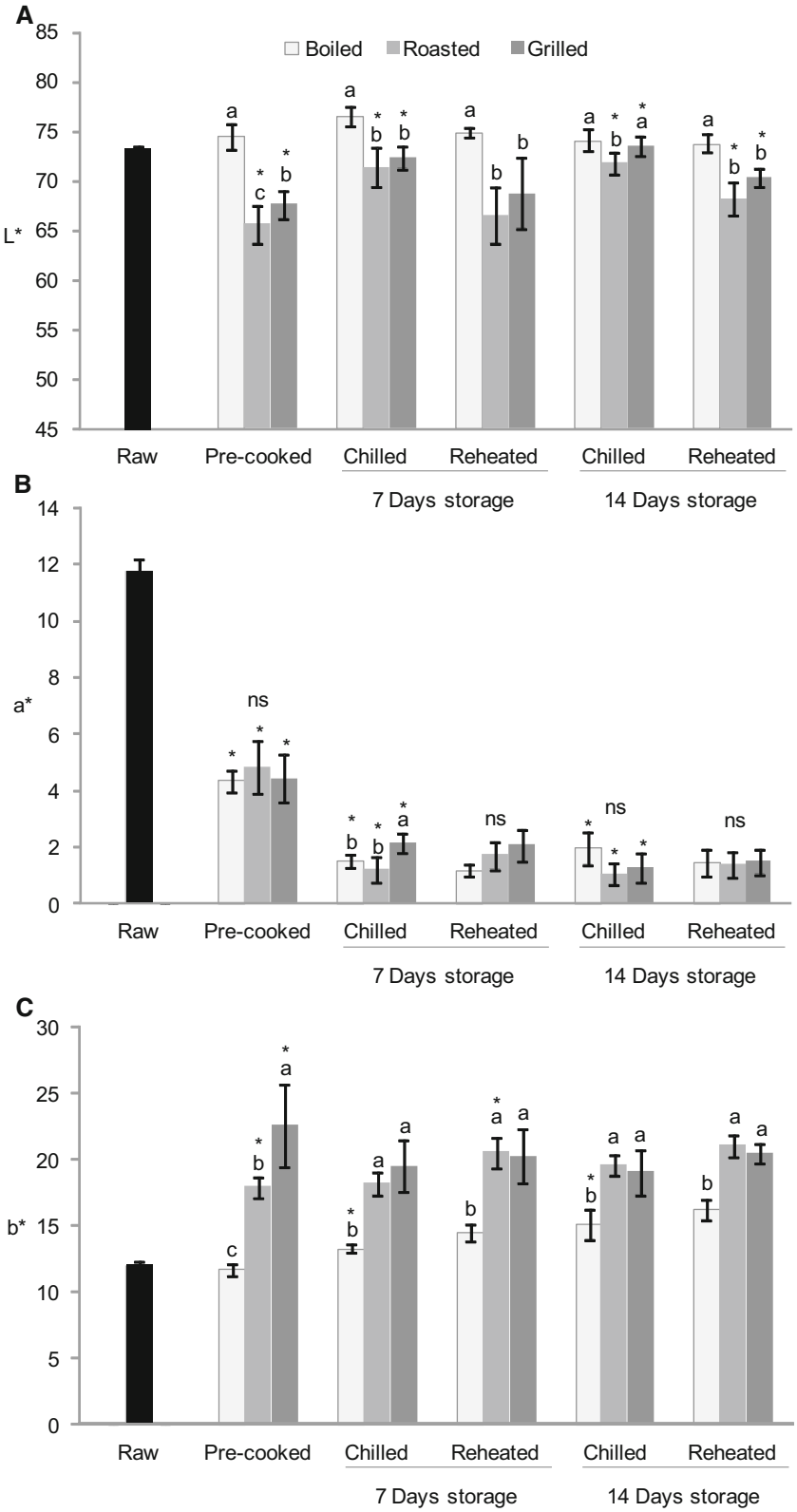

Fig. 2 Evolution of lightness (**a**), redness (**b**) and yellowness (**c**) of pre-cooked, chilled (for whether 7 or 14 days at +4 °C) and reheated chicken patties. *Different letters* on *top* of *bars* denote significant differences ($p < 0.05$) between pre-cooking methods within a particular processing stage. *ns* No significant differences between pre-cooking methods within a particular processing stage ($p > 0.05$). An *asterisk* on *top* of a *bar* denotes significant differences ($p < 0.05$) between that processing stage and the immediately previous one within a particular pre-cooking method

proposed above to explain the higher TBARS values in BL samples than in the patties subjected to the other pre-cooking methods. Interestingly, temperatures above 100 °C, as applied to RT and GR treatments, are indicated as inhibitors of the development of WOF (Bailey and Um 1992). In fact, cooking at temperatures above 100 °C led,

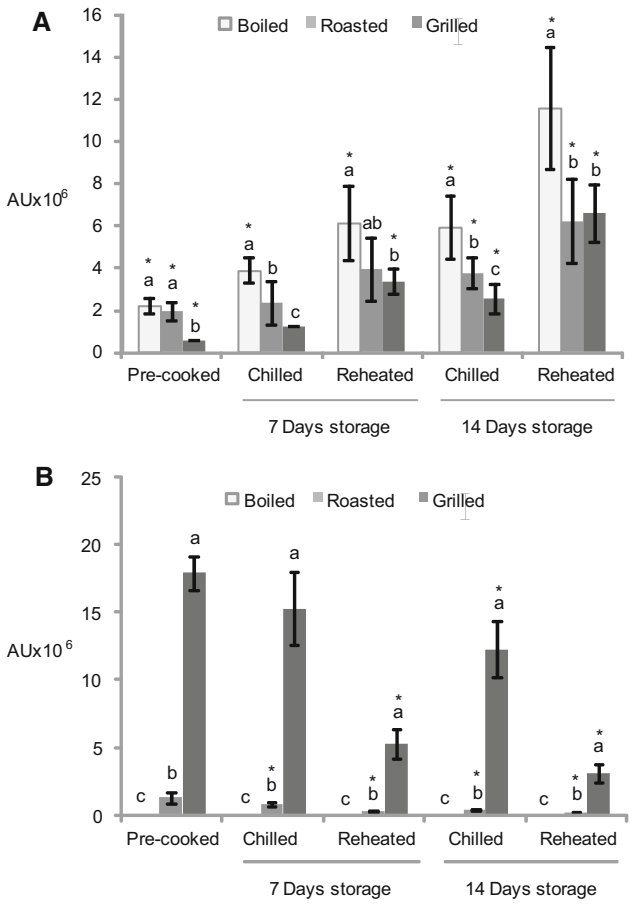

Fig. 3 Odor-active volatiles (Area Units, AU × 10^6): lipid-derived carbonyls (**a**) and Maillard-derived compounds (**b**) of pre-cooked, chilled (for whether 7 or 14 days at +4 °C) and reheated chicken patties. *Different letters* on *top* of *bars* denote significant differences ($p < 0.05$) between pre-cooking methods within a particular processing stage. *ns* No significant differences between pre-cooking methods within a particular processing stage ($p > 0.05$). An *asterisk* on *top* of a *bar* denotes significant differences ($p < 0.05$) between that processing stage and the immediately previous one within a particular pre-cooking method

in general, to a lower formation of lipid-derived volatiles and an enhanced formation of other group of volatiles derived from the Maillard reaction. The formation of Strecker aldehydes, namely, methyl propan-2-al, methyl butan-2-al, methyl butan-3-al and benzaldehyde, was more intense in GR samples, followed by far, by RT samples (Fig. 3b). No trace of these compounds was found in the headspace of BL samples. These Strecker aldehydes, formed as a result of the oxidative deamination of free amino acids in the presence of dicarbonyls, are typical volatile components of cooked meats (Domínguez et al. 2014; Estévez et al. 2003; Estévez et al. 2011; Roldán et al. 2014a, b). Methyl butan-2-al and methyl butan-3-al, found in large quantities in GR samples, are potent odorants contributing specific and generally pleasant flavor notes (Campo et al. 2006; Madruga et al. 2009). The highest concentration of Strecker aldehydes, found in the headspace of freshly pre-cooked GR and RT samples, decreased during the following processing stages with a remarkable loss of volatiles in the final reheating stage. Interestingly, WOF development in pre-cooked meats is not only believed to be the result of an increase of lipid-derived volatiles; a concurrent loss of meaty flavor is also playing a role (Byrne et al. 2002; Campo et al. 2006). Byrne et al. (2001a, b) attributed the reduction in 'meatiness' to the loss of sulphur-containing amino acids and other sulphur compounds. This event was confirmed in the present samples through the analysis of free thiols (data not shown). The evolution of Strecker aldehydes, formed during pre-cooking at T > 100 °C, and partially lost during the subsequent processing may have also contributed to impair the odor and flavor of patties since this Maillard-derived volatiles have been reported to impart meat aromas (Pegg and Shahidi 2012). These volatile components and their evolution during processing may have an influence in the odor liking and overall acceptance of the products as described below.

Odor liking of chicken patties during pre-cooking, chilling and reheating

The odor liking of the chicken patties was assessed at all stages of processing (Fig. 4). Overall, no significant differences ($p > 0.05$) between the types of pre-cooking (BL, RT and GR) were found at any of the stages under study (pre-cooking, chilling and reheating). Though not statistically significant, the higher scores received by freshly pre-cooked GR samples may be related to the lower extent of lipid oxidation and a more balanced volatile profile in this samples. The scores given by the panelists to the samples successively decreased during processing, reflecting a deterioration of the aroma that may be related to the development of WOF, as supported by the arguments previously reported ("Odor-active volatiles in chicken patties during pre-cooking, chilling and reheating" Section). The decrease of odor liking reached a significant extent after 14 days of refrigerated storage (+4 °C) in all samples irrespective of the pre-cooking method. According to the present results, the scores provided by the panelists shifted over time, from like slightly/neither liked, nor disliked to disliked slightly/moderately disliked. Other authors have also reported an impairment of the aroma profile of cooked meats during subsequent chilled that was generally linked by trained panelists to lipid oxidation, rancidity and WOF (Byrne et al. 2001a, b; Konopka et al. 1995; Mohammad Nisar et al. 2010). However, there is little information on how these changes can actually affect the consumers liking and acceptability. While it is proven that odor liking decreases with storage time and processing

Fig. 4 Odor liking of pre-cooked, chilled (for whether 7 or 14 days at +4 °C) and reheated chicken patties. *ns* No significant differences between pre-cooking methods within a particular processing stage ($p > 0.05$). An *asterisk* on *top* of a *bar* denotes significant differences ($p < 0.05$) between that processing stage and the immediately previous one within a particular pre-cooking method

stages, the relationship between consumers' perception and chemical changes analyzed in the present study is not straightforward. The significant differences observed between pre-cooking methods in terms of TBARS and volatiles were not reflected in the sensory analysis. Also the remarkable differences in MRPs may have had an influence since many of these compounds act as free radical scavengers and have been proposed to control, specifically, the deterioration of flavor in pre-cooked meats (Byrne et al. 2002). Additional chemical analysis or further sensory assessments (i.e. flavor liking) may contribute to a better understanding of these complex phenomena.

Conclusions

The present results showed the relevance of the refrigerated storage and its length, on the chemical deterioration of pre-cooked chicken patties. According to the TBARS numbers and the loss of redness, refrigerated storage has proven to be more influential on lipid oxidation than reheating in a microwave. Selecting a particular pre-cooking method has an impact on the extent of lipid oxidation, the color of patties and the aroma profile of RTE chicken patties. It seems unavoidable to control the storage conditions for inhibiting the development of oxidative reactions in RTE meat products. Further studies will be designed to check the effectiveness of antioxidant strategies (modified atmosphere packaging and phytochemicals) against lipid oxidation and consumer rejection.

Acknowledgments The authors are thankful to the CNPq and CAPES for the support through the projects 474300/2011-0 and 401167/2014-3. The authors also thank the project IB13132 funded by "Gobierno de Extremadura—Consejería de Economía, Competitividad e Innovación" cofinanced by "Fondo Europeo de Desarrollo Regional (FEDER)".

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