



Effects of USDA beef quality grade and cooking on fatty acid composition of neutral and polar lipid fractions

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ARTICLE INFO

Article history:

Received 8 May 2014

Received in revised form 10 October 2014

Accepted 16 October 2014

Available online 22 October 2014

Keywords:

Beef

Fatty acids

Flavor precursor

Lipids

USDA quality grade

ABSTRACT

The effects of USDA beef quality grade (QG; Prime, Low Choice, and Standard; $n = 8$) and cooking (RC) on fatty acid (FA) concentrations (mg/g dry matter) and percentages of neutral and polar lipid fractions (NL and PL, respectively) from strip steaks were explored. An increase in QG led to an accumulation of most FA, especially in the NL fraction ($P < 0.001$). Common effects on FA percentages were two-way interactions of either QG or RC with LF ($P \leq 0.019$). Fatty acids were affected differently by QG and RC depending on their originating LF. Mono-unsaturated fatty acid (MUFA) and polyunsaturated fatty acid (PUFA) percentages of the PL were dependent on QG ($P \leq 0.014$). Cooking and QG had minimal impact on FA percentages of the NL, however, greatly influenced PL MUFA and PUFA percentages ($P < 0.001$). There was evidence indicating that dry heat cookery affected not only PUFA, as generally thought, but also the MUFA of PL fraction.

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1. Introduction

Fatty acid composition is an important factor of beef nutritional value and sensory quality attributes (Wood et al., 2003). Oxidation of lipid FA has a profound impact on sensory quality attributes (Addis, 1986). Lipid oxidation is initiated through the removal of a labile hydrogen atom from an individual FA chain, producing a free radical that rapidly forms a peroxyradical with oxygen (Min & Ahn, 2005). The peroxyradical subsequently removes an additional hydrogen atom from another FA chain to form a hydroperoxide. As a result a new free radical is formed and further degradation of FA is perpetuated (Min & Ahn, 2005). Oxidation of lipids is commonly believed to occur during storage and cooking. Typically oxidation during storage is believed to produce volatile off-flavors and off-odors. Interestingly, the positive volatile flavors and aromas that are produced during cooking follow the same basic reaction pathways as oxidation during storage (Ladikos & Lougovois, 1990). However, subtle variation in thermal and storage oxidation mechanisms produces differing volatile mixtures (Mottram, 1987). Unlike prolonged storage oxidation of FA, thermal oxidation usually induces the dimerization of lipid degradation products and even the non-oxidative decomposition of SFA at a rapid rate to produce desirable volatile compounds, such as saturated and unsaturated aldehydes and

ketones, important components of cooked flavor (Mottram, 1998; Nawar, 1984; Selke, Rohwedder, & Dutton, 1977, 1980).

Polyunsaturated fatty acids have lower melting points and are more susceptible to oxidation than MUFA and SFA. Intramuscular lipids are composed of the NL primarily consisting of triglycerides and the PL containing mostly phospholipids. The FA composition of the PL fraction contains a large proportion of PUFA. Polar lipids are known to be more susceptible to oxidation (Mottram, 1998) and the PUFA content of PL is the primary substrate of rancidity development (Igene, Pearson, Dugan, & Price, 1980). The PUFA in the PL exhibit similar susceptibility to thermal oxidation where cooking affects the PL to a greater extent than it does the NL (Terrell, Suess, Cassens, & Bray, 1968).

Intramuscular fat content is increased primarily through accumulation of FA in the NL (Wood et al., 2008). An increase in beef intramuscular fat content in *Longissimus lumborum* beef steaks has been associated with increased flavor liking by consumers or flavor intensity rated by trained panelists (Emerson, Woerner, Belk, & Tatum, 2013; Garmyn et al., 2011; Hunt et al., 2014; Lorenzen et al., 2003, 1999; O'Quinn et al., 2012; Savell et al., 1987; Smith, Savell, Cross, & Carpenter, 1983; Smith et al., 1985). However, benchtop studies have repeatedly found that increased intramuscular fat rarely produces profound increases in volatile flavor compounds (Cross, Berry, & Wells, 1980; Mottram & Edwards, 1983; Mottram, Edwards, & Macfie, 1982).

Previous studies have focused on relationships between animal diet and the FA composition of lipid fractions (Duckett, Wagner, Yates, Dolezal, & May, 1993; Larick & Turner, 1990; Larick, Turner, Koc, & Crouse, 1989; Warren et al., 2008). In addition, much attention has

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been focused on nutritional value related to changes in FA composition during cooking (Alfaia et al., 2010; Badiani et al., 2002; Echarte, Ansorena, & Astiasaran, 2003; Gerber, Scheeder, & Wenk, 2009; Poon, Durance, & Kitts, 2001; Sarries, Murray, Moloney, Troy, & Beriain, 2009). However, few studies have examined the effects of cooking on FA of different lipid fractions (Duckett & Wagner, 1998; Terrell et al., 1968). As part of a comprehensive investigation on beef flavor contributing compounds, it was the objective of this study to determine how USDA quality grade and cooking changed FA composition, as potential flavor precursors, and whether the hypothesized effects varied by lipid fractions (LF).

2. Materials and methods

2.1. Product selection

Twenty-four beef strip loins (*L. lumborum*; Institutional Meat Purchase Specifications # 180, NAMP, 2010) were collected from carcasses of three USDA quality grades (Prime, Low Choice, and Standard; USDA, 1997; $n = 8$) from “A” maturity animals in the Midwest region of the US. Carcass marbling score was determined by trained individuals through comparison of visual marbling within the *Longissimus* muscle (LM) at the 12th and 13th ribs with official USDA marbling photographs (National Cattlemen's Beef Association, Centennial, CO, USA). Marbling scores [Prime (Slightly Abundant⁰⁰ or greater), Low Choice (Small⁰⁰ to Small¹⁰⁰), and Standard (Traces¹⁰⁰ or lower)], lean maturity (A⁰⁰ to A¹⁰⁰), skeletal maturity (A⁰⁰ to A¹⁰⁰), fat thickness (cm), LM area (cm²), hot carcass weight (kg), and percentage of the kidney, pelvic and heart fat were all collected to determine the USDA quality and yield grades (USDA, 1997; Table 1). Strip loin subprimals from the selected carcasses were vacuum-packaged (Barrier shrink bags, Sealed Air Corporation, Elmwood Park, NJ, USA) and transported to the Gordon W. Davis Meat Laboratory, where they were aged at 2 to 4 °C in the absence of light for 21 days postmortem before fabrication.

2.2. Fabrication and sample preparation

Strip loins remained in sealed vacuum packaging until fabrication on day 22 postmortem. Strip steaks were cut to 2.54-cm thickness and trimmed to 0-cm external fat thickness. Posterior steaks containing the *Gluteus medius* muscle were excluded. Within each strip loin, four steaks were cut from the anterior end of each strip loin after removal

of a “face steak” to straighten the anterior end. Anterior steaks numbering 1 and 3 were taken as raw samples and steaks numbering 2 and 4 were designated for cooking. Cooking was performed on an electric clamshell grill (George Foreman, Original Next Grilleration, model GRP99, George Foreman, Westmont, NJ, USA) to a medium degree of doneness (71 °C; AMSA, 1995), monitored by a Cole Parmer Type J thermocouple (Vernon Hills, IL, USA). Remaining external fat, accessory muscles, and connective tissues were removed from all cooked and raw steaks, leaving only the separable lean tissue of the *L. lumborum* muscle. The trimmed cooked and raw steaks were cubed, frozen in liquid nitrogen, and homogenized to a fine powder. The homogenized samples were stored at −80 °C until subsequent analyses.

2.3. Chemical analysis

Total lipids were extracted from 1-g homogenates of either raw or cooked samples using a modified Folch method (Folch, Lees, & Stanley, 1957). The extracted lipids were fractionated using a Resprep® silica gel cartridge (Restek Corporation, Bellefonte, PA) by being dissolved in approximately 2 mL of chloroform, loaded onto the cartridge. The NL was eluted first by 10 mL of chloroform and the PL was subsequently eluted by 15 mL of methanol (Juaneda & Rocquelin, 1982). Both lipid fractions were dried under a gentle nitrogen stream at 40 °C and stored at −80 °C until the subsequent fatty acid derivatization.

Fatty acids in the NL were saponified and derivatized to fatty acid methyl esters (FAME) using sodium methoxide in methanol (Li & Watkins, 2001), whereas the saponification and derivatization of FA in the PL were performed with methanolic potassium hydroxide (Maxwell & Marmer, 1983). Linolelaidic (18:2 $n - 6$ trans) methyl ester (Cat # FLSA-093, Ultra Scientific, N. Kingstown, RI, USA) was used as the internal standard during the derivatization. Fatty acid methyl esters were analyzed on an Agilent Technologies (Santa Clara, CA, USA) 6890 N series gas chromatography system equipped with an HP-88 capillary column (100 m × 0.25 mm i.d.; Agilent Technologies, Santa Clara, CA, USA) and a flame-ionization detector. Fatty acid methyl esters were identified by authentic FAME standards (Supelco® 37 Component FAME Mix, Sigma-Aldrich, St. Louis, MO, USA) and quantified by an internal standard calibration method. Concentrations of individual FA were calculated as milligram per 1 g of dry matter. Total FA concentration (mg/g dry matter) was also calculated for each fraction and for the entire FA composition. Percentages of FA were computed by dividing the individual FA concentration (mg/g dry matter) by the corresponding LF concentration (mg/g dry matter) then multiplying by 100. Percentages of NL and PL fractions were calculated by dividing the LF concentrations (mg/g dry matter) by the total FA concentration (mg/g dry matter). The common names and corresponding abbreviations of individual FA are listed in Table 2.

2.4. Statistical analysis

A split-split-plot design was used with QG, subprimal (strip loin), raw vs. cooked (RC), and lipid fractions (LF) serving as main factor, experimental unit or whole plot, split-factor, and split-split-factor, respectively, for the statistical analysis of percentages and concentrations of individual FA and FA categories. However, a split-plot design was used to analyze the percentages of LF (based on entire FA composition; using QG and RC factors) and the differences in LF concentrations between cooked and raw steaks (mg/g dry matter; using QG and LF factors). The effects of QG, RC, LF, and their interactions on concentrations and percentages of individual FA, FA categories, and LF were statistically analyzed by SAS version 9.3 (SAS Institute, Inc., 2012; Cary, NC, USA). Analysis of variance was based on a generalized linear mixed model, estimated by the GLIMMIX procedure of SAS. Denominator degrees of freedom were calculated using the Kenward–Rogers approximation. Means were separated by protected t-test using the LSMEANS

Table 1
Carcass characteristics of USDA Prime, Low Choice, and Standard quality grades ($n = 8$).

Measurement	Prime	Low Choice	Standard	Std. error ¹
Hot carcass weight, kg	381.5	374.4	377.2	11.2
LM area ² , cm ²	80.6 ^b	83.7 ^b	97.3 ^a	3.2
12th-rib fat, cm	1.6 ^a	1.5 ^a	0.8 ^b	0.18
KPH ³ , %	3.1 ^a	3.0 ^a	2.1 ^b	0.19
Marbling ⁴	774.2 ^a	429.2 ^b	264.6 ^c	12.8
Calculated yield grade	3.1 ^a	1.7 ^b	1.0 ^b	0.24
Skeletal maturity	48.3	35.0	42.5	3.9
Lean maturity	48.3	48.3	57.5	3.4
Overall maturity	48.3	41.7	50.0	3.3
Intramuscular fatty acid ⁵ , %	9.7 ^a	5.8 ^b	2.9 ^c	0.6

^{a,b,c} Means within a row lacking a common superscript differ ($P \leq 0.05$).

¹ Pooled standard error of means. Standard errors used for the protected t-test might differ because of heterogeneous variances.

² Area of the *Longissimus* muscle (LM) at the 12th and 13th ribs.

³ Percentage of the kidney, pelvic and heart fat of the carcass.

⁴ Marbling assessed at LM surface between the 12th and 13th ribs by comparison with official USDA marbling photographs (National Cattlemen's Beef Association, Centennial, CO, USA). Marbling score units: 200 = Traces⁰⁰; 300 = Slight⁰⁰; 400 = Small⁰⁰; 500 = Modest⁰⁰; 600 = Moderate⁰⁰; 700 = Slightly Abundant⁰⁰; and 800 = Moderately abundant⁰⁰.

⁵ Calculated as g of total fatty acids g per 100 g of raw *Longissimus lumborum* muscle tissue.

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