AN ABSTRACT OF THE THESIS OF

Nathan B. Parker for the degree of Master of Science in Animal Science presented on November 21, 2016.

Title: The Effects of Differing Hazelnut Concentrations in Hog Finishing Rations with Respect to Pork Shelf-life and Fatty Acid Composition

Abstract approved:

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John Killefer

Commercial hog diets in the United States commonly contain lipid sources high in polyunsaturated fatty acids, most notably linoleic acid (18:2). This may result in greater deposits of linoleic acid in pork adipose tissue, contributing to an increased potential for lipid oxidation, high n-6/n-3 fatty acid ratio and increased fat softness. These factors lead to detrimental effects on shelf-life, potential negative nutritional impacts on humans and yield loss, respectively. The hazelnut is a crop abundant in nutritionally beneficial oleic acid (18:1) and the antioxidant α-tocopherol. Due to aesthetic or conformational characteristics, a cull portion of this crop is thought to be undesirable for human consumption, and offers a relatively low-cost potential feedstuff for livestock. Altering the fatty acid profile of pork to reduce proportions of linoleic acid and increase oleic acid presents the potential to improve shelf-life and impart a favorable nutritional profile in pork tissues. With this in mind, the objective of our study was to explore the effects of differing concentrations of cull hazelnuts as a lipid source in hog finishing rations, and their influence on pork shelf-life and fatty acid composition.

Cull hazelnuts (95% kernel, 5% shell) were obtained and ground for replacement use in a commercially-sourced hog finishing ration. Berkshire-cross hogs (n=15, avg 97 Kg) were randomly assigned to one of three treatment groups (5/treatment): basal diet fed commercial pelleted finishing ration with 0% hazelnut composition (H0), 15% by overall weight hazelnut composition (H15), and 30% by overall weight hazelnut composition (H30), respectively. Hogs were fed *ad libitum* for 42d and then slaughtered. The *Longissimus* from one side of each hog was extracted 72 hr postmortem, vacuum-packaged, held at 3 ºC for 4 d to simulate transportation, and then sliced into 2.54 cm thick chops. Chops were packaged in polystyrene trays and overwrapped with O_2 permeable film, placed into a simulated retail display with continuous fluorescent lighting (3500K CCT, 1600-2200 lux) and held at 3 °C. Instrumental color was evaluated daily with a portable spectrophotometer. Samples were removed from display at days 0, 2, 4 and 6 for determination of lipid oxidation by thiobarbituric acid reactive substances (TBARS). Additional samples were excised to measure fatty acid composition, α-tocopherol content and total phenols. Data were analyzed as a completely randomized design, and each hog served as the experimental unit. Diet treatment was denoted as the main effect, with analysis day serving as a repeated effect in the case of shelf-life analyses.

Redness (CIE a^*) values in chops declined during retail display for all treatments, however rate of decline based on treatment did not differ. Lipid oxidation (TBARS) was suppressed ($P<0.05$) at d 6 in both H15 and H30 chops compared to H0. Total phenols were not different ($P>0.05$) between diet treatments, however α-tocopherol levels were 82 and 130% higher ($P<0.05$) in H15 and H30, respectively, than H0. Palmitic acid (16:0) levels diminished ($P<0.05$) in H30 pork, while oleic acid (18:1) increased ($P<0.05$) from 43.7% in H0 to 48.2% in H15, and 50.4% in H30 in subcutaneous fat. No significant changes ($P>0.05$) in linoleic acid (18:2) or n-6/n-3 ratio were identified.

Through the inclusion of hazelnut feed supplementation, the fatty acid composition of pork improved nutritionally via increases in oleic acid (18:1) and decreases in palmitic acid (16:0); however, no other definite benefits were identified

in this study. The suppression of TBARS can likely be attributed to an increase in α-tocopherol content in muscle, yet suppression was not significant enough to produce discernable effects on shelf-life when evaluated for instrumental color and purge loss.

The Effects of Differing Hazelnut Concentrations in Hog Finishing Rations with Respect to Pork Shelf-life and Fatty Acid Composition

by

Nathan B. Parker

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Head of the Department of Animal and Rangeland Sciences

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Nathan B. Parker, Author

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1. INTRODUCTION

Quality and nutritional composition are paramount when marketing safe, wholesome meat products to consumers. These are influenced by a variety of factors, with some even prevalent prior to the birth of the animal. Producers wishing to increase the financial return on their livestock may manipulate these factors, e.g. through various new and/or modified feeding programs.

The animal's diet is one of the most influential factors on meat characteristics and quality; both ruminants and non-ruminants will absorb some components of their diet, although the latter does so more readily than the former. Consequently, feeds with substantial antioxidant concentrations or those having a unique fatty acid composition can be instrumental in regard to meat quality, nutritional composition and flavor (Wood & Enser, 1997). This concept has been studied previously, utilizing various grass seeds or oils with nutritionally advantageous fatty acid compositions as a supplemental nutritional source (Teye et al., 2006). Tree nuts, however, have been rarely studied as a potential feed source in livestock finishing rations.

The hazelnut is of interest as a candidate to improve meat quality and nutrition, specifically with respect to Oregon, which produces 99% of the entire US yield, equaling 36,000 tons with a value totaling $120,600,000 in 2014 (United States Department of Agriculture, National Agricultural Statistics Service). Whereas hazelnuts are primarily sold for human consumption, a portion of the hazelnut yield each year is deemed unfit for consumer sale due simply to aesthetic or conformational characteristics, yet still contains the same nutritive value. These byproducts possess potential to be used in livestock feed.

The hazelnut's capacity to positively affect meat quality and nutrition is due many factors. The fatty acid composition found in hazelnuts offers a unique profile which contributes to extending shelf-life and improving the nutritional content of pork and pork products (Kris-Etherton et al., 1999; Parcerisa et al., 1998; Ruiz-Carrascal et al., 2000; Wood et al. 2004a). Various antioxidant compounds can also

be found in the hazelnut, presenting the opportunity to improve shelf-life and preserve quality (Maguire et al., 2004; Monagas et al., 2009).

Advantages to human health through an improved nutritional profile in pork products, in concert with enhanced meat sustainability due to reduced incidence of spoilage and prolonged shelf-life, and a unique flavor profile imparted by compounds in hazelnuts are some of the potential benefits to hazelnut inclusion in livestock diets if integrated effectively. These advantages could lead to an increase in value and marketability of hazelnuts, hazelnut byproducts, and meat products derived from hazelnut-fed livestock. The following review will closely examine information pertinent to the aforementioned topics.

2. LITERATURE REVIEW

Structures of fatty acids and fatty acid terminology

Food lipid terminology, classification and notation are best defined by Akoh (1998). Muscle food lipids found in meat sources typically consist of 12-24 carbon atoms which contain a polar carboxylic acid group (COOH) at one end of the chain, and a nonpolar methyl group (CH_3) at the opposing end. Fatty acids designated as saturated fatty acids (SFA) are denoted by the lack of any carbon double bonds (Figure 1). Conversely, if a carbon atom contains one or more double bond, it is then classified as an unsaturated fatty acid (UFA). If only one double bond is present, the fatty acid is designated as a monounsaturated fatty acid (MUFA) (Figure 2). If the fatty acid contains two or more double bonds, it is then classified as a polyunsaturated fatty acid (PUFA) (Figure 3). Furthermore, atomic positioning of doubly bonded atoms or groups in the molecular reference plane is denoted by either *cis* (hydrogen atoms on the same side) or *trans* (hydrogen atoms on opposing sides) designations (Figure 4).

Although many different fatty acid name classifications exist, only a few of these will be used for the purpose of this thesis. Shorthand notation commonly helps identify fatty acids. For example, if a fatty acid contains 16 carbon atoms with one double bond, the shorthand notation would be written as 16:1. In addition to shorthand notation, common or trivial names are used for fatty acid identification. For an individual fatty acid containing 16 carbon atoms and one double bond (16:1), the trivial name of palmitoleic acid will be given. Other frequently used common fatty acid names include stearic acid (18:0), oleic acid (18:1), linoleic acid (18:2), and linolenic acid (18:3).

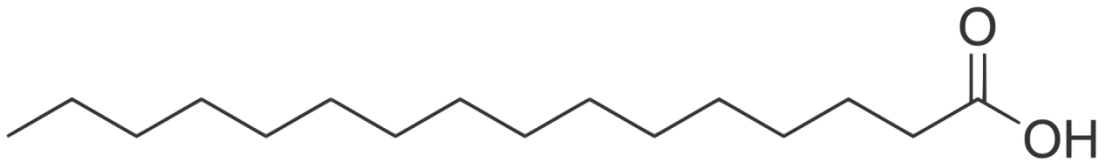

Figure 1. Atomic structure of saturated fatty acid- palmitic acid (16:0). Palmitic acid is denoted by 16 carbons without any double bonds. *Image courtesy of Wikimedia Commons.*

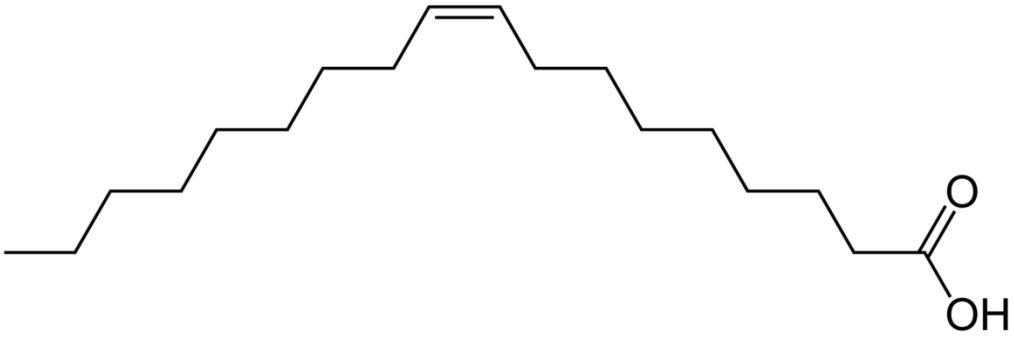

Figure 2. Atomic structure of monounsaturated fatty acid- oleic acid (18:1n-9). Oleic acid is denoted by 18 carbons, with one double bond at the 9th carbon from the methyl (CH_3) end. *Image courtesy of Wikimedia Commons.*

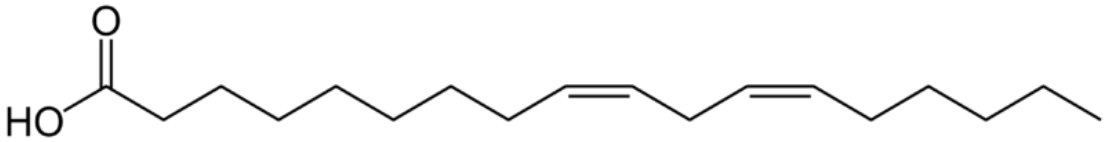

Figure 3. Atomic structure of polyunsaturated fatty acid- linoleic acid (18:2n-6). Linoleic acid is denoted by two double bonds, with the first occurring at the 6th carbon from the methyl (CH_3) end. *Image courtesy of Wikimedia Commons.*

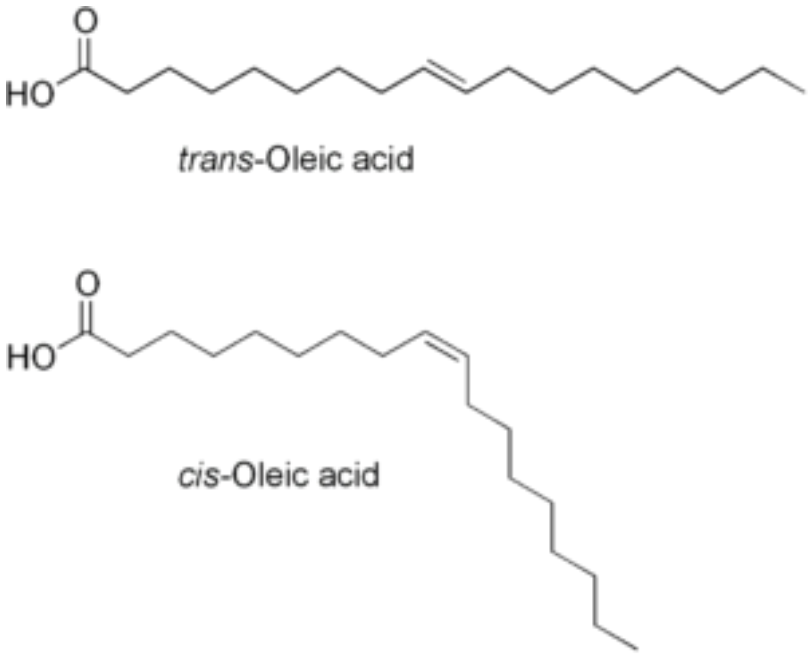

Figure 4. Atomic structure of oleic acid (18:1n-9) in either *cis* or *trans* configuration. Distinctive curve in carbon chain is noted in *cis* (same side) configuration. *Image courtesy Wikimedia Commons.*

To further identify fatty acids with double bonds present, the n-minus system will be used. The n-minus designation identifies the position of the first double bond placement from the fatty acid's nonpolar methyl end (CH_3) by subtracting from the total number of carbons (n) present in the chain. For example, the first double bond in linolenic acid (18:3) is three carbons from the methyl end of the carbon chain. In shorthand notation, this would be written as 18:3n-3. Additionally, the n-minus designation of fatty acids will indicate their function and purpose within the body (Akoh, 1998).

Other physical properties of fatty acids, such as melting point, are determined by chain length and double bonds. Increases in fatty acid melting points can be observed as the number of carbons increases. Moreover, the presence and number of double bonds has a much more profound effect on fatty acid melting point. As double bonds move towards the center of the carbon chain, a reduction in melting point will be the outcome, with the effect being more profound for double bonds in the *cis* configuration as opposed to those in the *trans* configuration (Nichols & Sanderson, 2003). For example, the melting point of stearic acid (18:0) is 69.6˚C, whereas oleic acid's (18:1) melting point is 13.4˚C. Linoleic acid (18:2), by comparison, has a much lower melting point of -5˚C, and linolenic acid (18:3) even lower at -11˚C (Wood et al., 2004a).

Fatty acid composition of meat products

Many genetic and environmental factors play an instrumental role in influencing the fatty acid content of different meat animal species (De Smet et al. 2004). Fatty acid profiles vary depending on the species in which they're found. Common meat animal species such as beef and lamb (ruminants) contain higher levels of saturated fatty acids (SFA) in muscle and adipose tissue compared to that of pork (non-ruminants), which contain elevated levels of polyunsaturated fatty acids (PUFA) (Wood et al., 2008). This is due to the biohydrogenation processes within ruminant species which hydrogenate unsaturated fatty acids within the rumen.

Because of this process, ruminants typically have decreased levels of long chain n-3 PUFA compared to non-ruminants (Wood et al., 1999).

On average, intramuscular pork fatty acid composition from commercially-sourced hogs consists of 34-38% SFA, 42-48% MUFA, and 12-20% PUFA. Of these different types of fatty acids, palmitic acid (16:0) comprises the majority of SFA, while oleic (18:1) and linoleic (18:2) acids make up the majority of MUFA and PUFA, respectively (Kouba et al., 2003)

A study conducted by Enser et al. (1996) further illustrates the difference in fatty acid composition between ruminants and non-ruminants. Beef, lamb and pork muscle and adipose samples derived from steaks and/or chops from each species were evaluated for relative fatty acid percentages. Pork linoleic acid (18:2n-6) content (percentage by total weight) in muscle and adipose tissue samples was significantly greater (14.2 and 14.3%, respectively) than that of beef (2.42 and 1.10%, respectively) and lamb (2.7 and 1.31%, respectively). Beef and lamb PUFA:SFA ratios in muscle tissues were significantly lower (0.11 and 0.15, respectively) than that of pork (0.58). Consequently, n-6:n-3 ratios in pork muscle samples were higher (7.48) than beef and lamb (2.11 and 1.32, respectively) (Enser, 1996).

Meat color and shelf-life

Fresh meat color is the most important factor in regard to consumer purchasing decisions at retail (Mancini & Hunt, 2005). Since the majority of meat products at retail are found in various forms of packaging, off odors and product texture are not readily detectable by consumers, making visual appearance the most prevalent indicator of wholesomeness and freshness, and the determining factor in whether or not the consumer purchases the product (Suman and Joseph, 2013). It has been reported that economic losses due to discarded beef retail products caused by product surface discoloration totals $1 billion annually (Smith et al., 2000). To aid in prolonging retail shelf-life and color stability of meat products to offset these economic losses, a complete understanding of myoglobin biochemistry is needed.

Myoglobin biochemistry and effect on meat color

Suman and Joseph (2013) give a comprehensive overview of myoglobin chemistry and function. Myoglobin (Mb) is a water-soluble heme protein consisting of a prosthetic heme and globin group, with eight helical portions comprising the globin chain in a coiled formation, enveloping the heme. Myoglobin's ability to bind oxygen is due to the heme within the heme crevice, whereas the globin chain protects protein functionality by mitigating water-solubility of the heme group and the heme iron (Fe) atom located within, protecting it from environmental factors and oxidation. Conjugated double-bonds within the heme group give Mb the ability to absorb varying spectra of visible light, which makes Mb primarily responsible for giving meat its red color, with hemoglobin and cytochrome also contributing to meat color, albeit to a lesser degree in livestock species. The heme iron atom in Mb occurs in either a reduced ferrous iron (Fe^{2+}) form, or as oxidized ferric iron (Fe^{3+}), and its six coordination sites give it the ability to bind with other molecules. Four sites in the Fe atom bind with pyrrole groups of the heme porphyrin ring, while a fifth site binds a proximal histidine, connecting the heme to the globin chain. The sixth coordination site of Mb's heme iron atom allows Fe to reversibly bind to ligands, namely oxygen (O), carbon monoxide (CO), and nitrogen oxide (NO) (Suman & Joseph, 2013).

Suman and Joseph (2013) further explain redox forms, color, and light absorbance spectra of myoglobin. With respect to fresh meat products, Mb exists in four primary redox forms: deoxymyoglobin (DeoxyMb), oxymyoglobin (OxyMb), carboxymyoglobin (COMb), and metmyoglobin (MetMb). The form which Mb takes on in fresh meat is principally dependent on molecular binding to ligands at the heme iron atom's sixth coordination site. OxyMb is bound by oxygen at the heme iron's sixth coordinate, whereas COMb interacts with carbon monoxide, and no ligands are bound in the DeoxyMb phase. Heme iron in these three forms of Mb is in the ferrous ($Fe2^{+}$) state. Metmyoglobin is an oxidized form of Mb in the ferric ($Fe3^{+}$) iron state, and it is occupied by a water molecule at the sixth coordinate and cannot interact with oxygen. Each redox form of fresh meat Mb lies between 500-600 nm on the color absorbance wavelength spectrum and possesses distinct absorption peaks which are

able to be measured instrumentally. Deoxymyoglobin experiences peak light absorption at 557 nm, while MetMb peaks are encountered at 503 nm. OxyMb and COMb each have two absorption peaks; OxyMb experiences peaks at 542 and 582 nm, respectively, while COMb peaks are seen at 543 and 581 nm, respectively. These peaks correlate to characteristic colors detectable to the human eye for each redox form of Mb. In DeoxyMb forms, meat appears as a dark purplish-red hue, while COMb and OxyMb forms, in the presence of CO and O which induce a "bloom" effect in fresh meat, take on a bright, cherry-red color which consumers find most appealing and acceptable. Metmyoglobin visual appearance is that of a brown color due to the oxidized ferric state of the heme iron, is largely considered undesirable to consumers at retail, and is a major reason why fresh meat products are discarded (Suman & Joseph, 2013).

Packaging impact on meat color

Retail packaging materials play a vital role in determining the color of the meat products packaged within (Suman & Joseph, 2013). Aerobic and anaerobic packaging methods are commonly used during retail display. Anaerobic packaging forms like vacuum-packaging do offer an extension of shelf-life over aerobic methods due to the lack of oxygen within the packaging; however, the dull purplish color of DeoxyMb in meat products using this packaging method is not visually ideal for consumers looking to purchase fresh product (Mancini & Hunt, 2005). Conversely, the exchange of oxygen and subsequent binding to Mb's heme iron induces the visually-appealing cherry-red color indicative of fresh meat in aerobic packaging (Mancini & Hunt, 2005). Some forms of packaging such as modified atmospheric packaging (MAP) are gaining popularity and prompt the same reaction with Mb in meat products by introducing the product to a controlled sealed environment of gases (high oxygen- ~80% O_2 and ~20% CO_2; low oxygen- ~0.4% CO, ~20-30% CO_2, with the rest comprised of N) that can prolong meat color stabilization (Cornforth & Hunt, 2008). Color stabilization can last anywhere from 14-21 days at retail using different MAP packaging methods (Suman & Joseph, 2013). Although MAP packaging

techniques offer shelf-life extension over high oxygen packaging materials, inherent disadvantages relating to negative perception of CO gas by consumers and masking of potential spoilage and rancidity may limit its use (Cornforth & Hunt, 2008). More commonly, O_2 permeable polyvinyl chloride (PVC) overwrap packaging, which allows for the transfer of oxygen through the film wrap to interact with Mb in meat products, is used to package meat products for retail sale due to its affordability and ease of use (Cornforth & Hunt, 2008). Although PVC packaging use is widespread, it offers the lowest duration of retail shelf-life (3-7 days) compared to other mainstream methods due to the product's high susceptibility to oxidation (Cornforth & Hunt, 2008). Since the shelf-life of meat products using this method of packaging over others (e.g. vacuum-packaging, MAP) is greatly diminished, it is imperative to explore ways to prolong the shelf-life of products in PVC overwrap packaging.

Measuring meat lipid peroxidation and color stability

As previously mentioned, lipid peroxidation of meat products is primarily affected by the fatty acid composition (degree of saturation) of the product and exposure to oxygen. Oxidized lipids produce free radical hydroperoxides, which are the main compounds of lipid oxidation, and which give way to secondary products such as aldehydes, ketones, alcohols and hydrocarbons (Akoh, 1998). To calculate degree of lipid peroxidation, a thiobarbituric acid reactive substances (TBARS) assay is typically used to measure the amount of malondialdehyde (MDA) - a byproduct of hydroperoxides- which reacts with thiobarbituric acid. As the level of MDA concentration in the sample increases, the sample has a higher degree of lipid oxidation. Commonly, TBARS assays will report the results as mg/kg MDA in the sample.

The American Meat Science Association's Meat Color Measurement Guidelines (2012) outlines how meat pigmentation is measured instrumentally. For pigment oxidation, instrumental or objective color evaluation measurements are taken to determine tristimulus L^*, a^*, and b^* color space values colorimetrically. L^* values represent brightness and are a measurement of lightness and darkness on the Z axis of

the color plane. *b** values range from negative (-) blue to positive (+) yellow values on the Y axis, and *a** values range from negative green values to positive red values on the X axis of the color plane, depicted in Figure 5. Colorimetric instrumentation employs an aperture which reflects standardized light off of the sample. The degree to which the light reflected off of each color space axis of the respective sample deviates from each axis' origin is assigned a hue color value, as shown in Figure 6. With respect to fresh meat, *a**, or redness, values are indicative of the degree of pigment oxidation in the sample. Higher redness values are associated with higher concentrations of OxyMb or CarboxyMb, while lower values typically represent Mb's transition to oxidized MetMb (AMSA, 2012).

Altering pork fatty acid profile and antioxidant content through the diet

As previously stated, since hogs are monogastrics (non-ruminants), they more readily absorb and deposit components of their diet into muscle and adipose tissue commonly consumed in the human diet than those of ruminant species (Wood, 2008). Due to this fact, numerous studies have sought to beneficially alter the fatty acid composition and antioxidant content of pork products through various feeding and supplementation programs in hog diets. Some of the aims of these studies were to examine protein and lipid oxidative stability of pork products, prolong retail shelf-life, and evaluate sensory attributes.

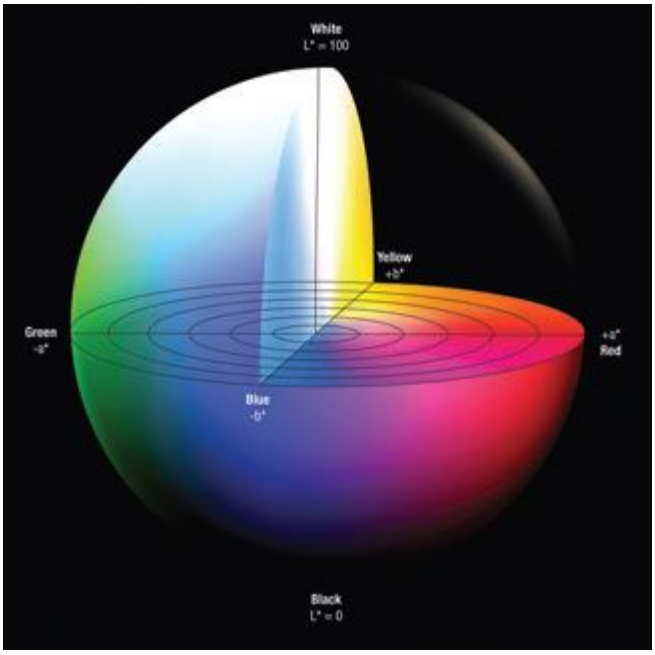

Figure 5. Three-dimensional color plane for CIE *L**, *b** and *a** color space values. *Image courtesy of Konica Minolta Sensing Americas.*

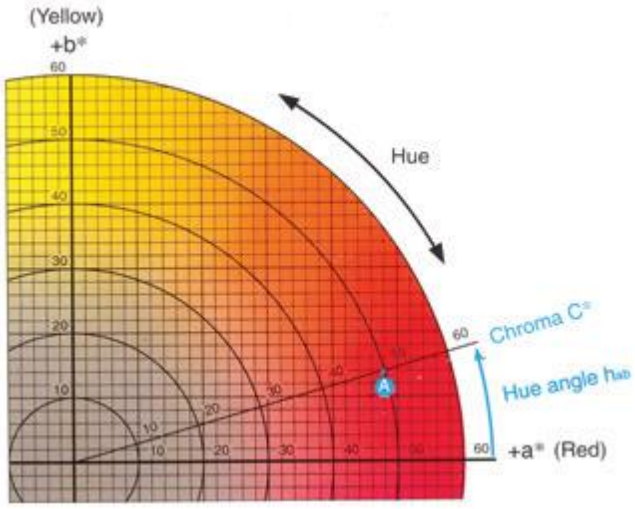

Figure 6. Diagrammatic representation of hue angle and chroma C* saturation index for color sample. CIE *a** and *b** values for sample are plotted at point A (47.63 and 14.12, respectively). *Image courtesy of Konica Minolta Sensing Americas*.

Fatty acid impact on pork shelf-life

Given that physical appearance of meat products, especially fresh, uncured products, plays a vital role in their ability to be sold at retail, many studies have sought to explore methods to prolong meat color stability and shelf-life through endogenous factors, namely livestock feeding programs. Of interest to this study are techniques which involve altering the fatty acid composition through the diet and incorporating feeds in livestock diets high in antioxidants, namely vitamin E (α-tocopherol), which are noted for their ability to delay lipid and pigment oxidation. The ability of these factors to prolong meat shelf-life will ultimately determine the acceptability and marketability of these products to consumers.

Linoleic content is of special interest concerning pork products. This is primarily due to the fact that over the past 100 years large-scale agricultural production has shifted towards producing commodities higher in levels of linoleic acid (18:2n-6), specifically seed oils, which are highly susceptible to lipid oxidation (Akoh, 1998). These linoleic-rich commodities, such as corn and soybean meal, are primary constituents in U.S. commercial hog finishing rations (Hoffman & Baker, 2011). Consequently, pork products derived from hogs fed high linoleic rations often experience elevated levels of linoleic acid in muscle and adipose tissue depots. These high linoleic pork diets can adversely affect human health (n-6:n-3 ratio) (Enser et al., 2000; Kouba & Mourot, 2011) and compromise the oxidative stability and shelf-life attributes compared to hogs fed higher concentrations of MUFAs (Isabel et al., 2003; Ventanas et al., 2007).

Researchers have sought to alter this trend of high linoleic diets in hogs by incorporating feeds higher in monounsaturated fatty acids, namely oleic acid (18:1n-9). A large number of these studies have centered on acorn inclusion in Iberian pig diets and their subsequent effect on pork shelf-life. Iberian hogs are a breed native to the Iberian Peninsula of Spain and Portugal, which are commonly reared on free-ranging acorn and grass diets (Cantos et al., 2003). With respect to fatty acid composition, acorns are noted for their high MUFA content, notably oleic acid, which comprises >63% of total fatty acids (Cantos et al., 2003). Iberian hogs are also shown

to readily deposit oleic acid constituents derived from acorn-sourced diets into meat tissues, which make up >55% total fatty acid content (Cantos et al., 2003).

Many studies have explored the impact that the acorn's fatty acid composition has on Iberian pork shelf-life and meat quality attributes. In a study by Cava and others (1997), the authors analyzed the fatty acid composition of pork tissues from hogs finished on an extensive acorn and grass *Montanera* diet, a *Recebo* acorn and commercial ration, and a *Cebo* standard commercial diet. The authors noted significantly greater deposits of MUFA in *Montanera* intramuscular and triglyceride lipid fractions of the *Masseter* muscle than that of Recebo and Cebo diets. Additionally, *Montanera* diets also experienced higher deposits of MUFA in *Masseter* muscle phospholipid fractions than *Recebo* and *Cebo* treatments, along with significantly lower levels of linoleic acid (18:2) than *Recebo* and *Cebo* diet treatments (Cava et al., 1997). Other studies observed similar deposits of MUFA and oleic acid in pork muscle and fat depots influenced by extensive acorn and pasture feeding programs compared to commercially-sourced concentrate rations (Ruiz et al., 1998; Andrés et al., 2001; Tejeda et al., 2002). Furthermore, Rhee and others (1990) found fresh pork loin chops (*Longissimus dorsi*) and roasts (*Semitendinosus*) sourced from hogs supplemented with high oleic sunflower oil (>85% oleic acid) at a level of 12% did not negatively affect lipid oxidation in chops and roasts when evaluated for TBARS during retail storage compared to products derived from hogs fed control (sorghum-soybean) diet. Additionally, high oleic supplementation did not unfavorably impact pork products with respect to palatability and cook loss (Rhee et al., 1990).

Antioxidants' role in pork shelf-life

Potentially more impactful to pork products and shelf-life are antioxidants and phenolic compounds, namely vitamin E in the form of α-tocopherol. A fat-soluble isomer, α-tocopherol is heralded for its anti-inflammatory properties, ability to naturally scavenge oxygen-producing free radicals, reduce lipid peroxidation and oxidative stress, and yield oxidative stability within the body (Tucker & Townsend,

2005). It is primarily found in dietary plant sources like olive oil, sunflower seeds and certain nuts (Tucker & Townsend, 2005). There is also evidence to suggest that dietary α-tocopherol intake and supplementation may reduce the risk of chronic diseases in humans such as cardiovascular disease (CVD), certain types of cancer and Alzheimer's (Morris et al., 2005; Jiang, 2014).

Iberian pork studies have noted the antioxidant effect that acorns impart to meat products with respect to lipid and pigment oxidation stability. Tejerina and others (2011) found acorn kernels used in Iberian hog diets contain elevated levels of antioxidants and phenolic compounds, namely γ-tocopherol, with α-tocopherol in lesser concentrations. However, common *Montanera* feeding programs incorporate a mixture of linolenic-rich (18:3n-3) grasses (*Brassicaceae*, *Geraniaceae*, and *Gramineae*) in Iberian hog diets, which are also high in α-tocopherol content. These antioxidants possess the ability to scavenge oxygen free radicals and mediate oxidative stability in pork meat tissues (Tejerina et al., 2011).

In a study by Cava and others (1999), the authors investigated the effect of extensive pasture-based acorn and grass Iberian feeding systems versus hogs reared in confinement on mixed concentrate diets supplemented with either 100 or 5 mg of α-tocopherol acetate, with 5 mg treatments serving as control. Muscles extracted from the ham (*B. femoris* and *Semimembranosus*) were analyzed for fatty acid composition, oxidative stability (TBARS) and sensory attributes. Hogs fed outdoors on acorns and grass possessed higher concentrations of oleic acid and overall MUFA in muscle samples than hogs fed mixed concentrate diets, along with lower levels of SFA compared to hogs finished on mixed concentrate rations. Furthermore, hogs fed extensive acorn and grass diets exhibited significantly greater accretion of α-tocopherol in muscle than 100 and 5 mg supplemented mixed concentrate diets, and also exhibited lower TBARS values than mixed concentrate diets. This is likely attributed not only to α-tocopherol content derived from grasses in extensive Iberian feeding regimes, but also to oleic acid content imparted by acorns. Muscle samples from acorn and pasture fed hogs experienced higher overall sensory evaluation scores than samples from hogs fed in confinement on mixed concentrate rations (Cava et al.,

1999). These results are in line with a previous study conducted by Rey, Lopez-Bote and Arias (1997), in which the authors analyzed Iberian hog muscle samples (*Longissimus dorsi*) from hogs fed an extensive acorn and pasture diet, and two other diet groups reared in confinement with mixed concentrate rations, and supplemented with either 100 or 10 mg/kg feed of α-tocopherol acetate, with 10 mg supplementation serving as the basal diet. When evaluated for metmyoglobin/ hydrogen peroxide lipid oxidation, microsomal samples from hogs raised extensively on acorn and pasture exhibited lower levels of oxidation after 2h of incubation than samples obtained from hogs receiving either 100 mg of α-tocopherol acetate supplementation or a basal diet (Rey, Lopez-Bote & Arias, 1997).

Of specific importance to this study is not only the effect that α-tocopherol content in pork muscle and lipid fractions has on lipid oxidative stability, but also on color stability. Antioxidants and α-tocopherol supplementation in livestock rations have been known to have color-stabilizing effects on beef (Chan et al., 1996; Lynch et al., 1999) and lamb (Wulf et al., 1995; Guidera et al., 1997) products; however, physiological differences exist between beef and lamb (ruminants) compared to pork (non-ruminants). As previously noted, fatty acid composition differs between ruminants and non-ruminants, thus it's important to explore the role that both antioxidants and fatty acid composition play with respect to color stability in pork.

Phillips and cohorts (2001) examined the role that α-tocopherol supplementation plays in mediating lipid and color oxidative stability in fresh pork products. Hogs in the study were assigned to either a control diet supplemented with 48 mg α-tocopherol acetate/kg feed, or a treatment group supplemented with 170 mg α-tocopherol acetate/kg feed. As expected, α-tocopherol concentrations in muscle samples from treatment diets were greater than control. TBARS values for unsalted ground patties sourced from the Boston butt were lower in samples from treatment hogs after 6d of refrigeration storage at 4˚C than control, and salted patties (1.5% salt) from treatment group also experienced lower TBARS values at 2, 4, and 6d of refrigerated storage than control samples. Although lipid oxidation was suppressed with α-tocopherol supplementation, no significant difference was detected with

respect to *a**, *b** and *L** color values between treatment and control salted and unsalted ground pork, and loin chop samples packaged either aerobically or using MAP methods (Phillips et al., 2001).

However, a study conducted by Tejerina and others (2012) evaluating color stability of *Longissimus dorsi* and *Serratus ventralis* muscles from Iberian hogs documented increased color stability due to antioxidant content in the feeding program. Muscles sourced from hogs fed on a *Montanera* (free-range extensive acorn and grass ~70-80d prior to slaughter) feeding program experienced higher *a** (redness) color values than samples derived from hogs fed on a *Recebo* (~40d reared outdoors on acorn and grass, last ~40d in confinement finished on mixed concentrate diet) program or an *Intensive* (~80d confinement and mixed concentrate feed) feeding program. Additionally, *Montanera* muscle samples contained higher concentrations of MUFA and oleic acid than those from *Recebo* and *Intensive* diets, as well as higher overall total phenolic compounds and antioxidant activity than *Recebo* and *Intensive* feeding systems (Tejerina et al., 2012). Furthermore, a study by Estévez, Morcuende and Cava (2003) reported higher *a** values in acorn and grass fed Iberian pig *Longissimus dorsi* samples during 10d refrigerated fluorescent retail display than samples from industrial hogs fed a commercial diet, as well as numerically higher concentrations of MUFA (48.0-50.6%) in muscle samples than industrially-raised hogs (40.25%). These findings suggest that instrumental pork meat color stability during storage and retail display may be achieved through feeding programs high in both MUFA content and antioxidant compounds.

Meat-derived food lipids and their nutritional value and function

Cichon (2003) details food-derived lipids and their function. For lipids derived from muscle foods, the primary form consumed in the human diet is that of triacylglycerol (TAG). TAG comprises the largest amount of fats stored within the body in adipose cells, and its molecular structure is denoted by three fatty acids bound via ester linkage to a glycerol structure. Phospholipids (PL) make up the

second largest group of fats, which account for ~2% of total fat composition, with sterols and other lipids making up much smaller and trivial amounts. PL are identified by an attached phosphate group, are extensively distributed in cell membranes, and serve essential functions in the body such as emulsification in bile (lecithin) and nervous system and brain function/protection (sphingomyelin). Virtually no free fatty acids are found in food lipids (Cichon, 2003).

With respect to the metabolic energy, food lipids offer humans and animals 9 kcal/g, whereas proteins and carbohydrates provide 4 kcal/g each. The amount of energy available from each FA is dependent on carbon chain length and degree of saturation. This is due to the metabolic oxidation processes each FA is subject to in the body. Therefore, FA available energy increases as degree of saturation and chain length increases. For example, stearic acid (18:0) has a higher degree of energy than that of oleic (18:1) acid, which in turn has more energy than that of palmitic acid (16:0) (Cichon, 2003).

The human body possesses the ability to synthesize FAs through enzymatic activity. These enzymatic processes either increase carbon chain length (elongation), or insert double bonds (desaturation) in FAs. However, certain FAs that are regular components of lipids found within the diet cannot be synthesized by animals or humans. Because these FA are vital to proper physiological function within the body, they are deemed essential fatty acids (EFA). Of particular interest are n-3 (omega-3) and n-6 (omega-6) PUFAs, specifically linoleic acid (18:2n-6) and α-linolenic acid (18:3n-3). Although linoleic and linolenic acids aren't inherent in humans or animals, they are present in plant dietary sources, and they can be synthesized via elongation and desaturations processes in both humans and animals. Inclusion of plant sources containing n-6 and n-3 FAs in the diet serve essential functions such as synthesizing steroid hormones, maintaining cell membranes, and regulating various cellular functions (Cichon, 2003). These EFAs also serve to transport fat-soluble vitamins (Vitamin A, D, E, & K) throughout the body and are essential in immune response in human and animal alike (Webb & O'Neill, 2008).

Nutritional impact of fatty acids in human diet

Fat content of meat products consumed by humans, especially in the Western diet, has become a major point of attention in recent years. The World Health Organization (WHO) recommends that daily dietary fat intake should be at least 15% of total energy consumed for most adults, and should not exceed 30%. Furthermore, WHO has specified that of this total fat intake, SFA should not exceed 10% of total energy consumed, while PUFA should make up 6-11% (n-6, 5-9%; n-3, 0.5-2%) total energy, and MUFA should account for roughly 9-15% (WHO, 2008). Additionally, ratios for PUFA:SFA (0.4-1.5) and n-6:n-3 (≤4) are generally accepted and recommended for optimal human health (Simopoulus, 2002; Wood et al., 2004a; Kang et al., 2005).

Numerous epidemiological and case-control studies have also corroborated the importance of appropriate fat intake ratios in the diet, especially that of n-6:n-3 and PUFA:SFA ratios. These are correlated to decreased risk of diseases in humans such as cardiovascular disease (CVD) and inflammation (Calder, 2004), cancer (Manson et al., 2012), type-2 diabetes and obesity (Todoric et al., 2006), lower LDL cholesterol (Chang et al., 2014) and proper brain function (Leaf et al., 2003)

To address health risks from high n-6 and SFA diets, concerted efforts have been made to increase levels of omega-3 fatty acids of meat products in recent years, in turn decreasing levels of n-6 and SFA and increasing nutritional value regarding ideal n-6:n-3 ratios and higher n-3 content (Enser et al., 2000; Kouba & Mourot, 2011).

Despite the nutritional benefits to humans consuming pork products from hogs supplemented with omega-3 fatty acids, which has primarily been investigated through the use of linseed and fish oil sources, sensory attributes and shelf-life in these pork products may experience negative effects (Ahn, Lutz, and Sim, 1996; Bryhni et al., 2002). Conversely, it's been shown that hogs fed diets high in MUFA do not impart adverse sensory or shelf-life characteristics to the meat (St. John et al., 1987; Rhee et al., 1990; Shackelford et al., 1990).

Nutritional significance of oleic acid

The study of oleic acid and its compositional properties are of importance not only for its benefits to human health, but also what it imparts to enhance the quality and shelf-life of meat products. Oleic acid (18:1), an omega-9 (n-9) MUFA, is the most abundant unsaturated fatty acid. It is a product of n-9 desaturase activity on stearic acid (18:0), and the precursor for other polyunsaturated fatty acid manufacture. It is obtained from plant, animal, bacterial, and algae sources, with the most abundant oleic acid food sources being olive oil, butter and tree nuts (Akoh, 1998).

Although not considered an EFA, oleic acid has demonstrated positive effects on human health. High concentrations of low-density lipoprotein (LDL) cholesterol derived primarily from SFA sources in the diet with its causal relationship to increased risk of atherosclerosis (heart attack, stroke, peripheral vascular disease) are well noted (Wasowicz, 2003). Conversely, increased presence of high-density lipoprotein (HDL) cholesterol in place of LDL is known to decrease risk of atherosclerosis (Assmann & Gotto, 2004). There is strong evidence that replacing carbohydrate sources with elevated levels of MUFA can increase high-density lipoprotein (HDL) levels as well as benefit insulin sensitivity in human diets (WHO, 2008). Other evidence suggests that human diets that replace SFA with MUFA possess the ability to lower LDL cholesterol concentration and total/HDL cholesterol ratio (WHO, 2008). In a study conducted by Grundy (1986), patients fed a diet high in monounsaturated fat experienced lowered total plasma cholesterol and low-density lipoprotein cholesterol (13 and 21%, respectively) compared to patients fed a high saturated fat diet. There is also evidence that high oleic diets, most notably those derived from olive oil, have the ability to decrease the risk of cardiovascular disease (CVD), stroke, and certain forms of cancer (Rozati et al., 2015).

The beneficial effects of MUFAs in the diet have prompted researchers to identify other viable dietary sources. Nuts are of special interest due to a favorable fatty acid profile which is low in SFA and high in UFA, especially MUFA in the form of oleic acid (18:1), which accounts for, on average, ~62% total fat energy (Kris-

Etherton et al, 1999). Kris-Etherton and others (2001) have also reported that diets in which various nuts were consumed had positive impacts on chronic heart disease through their ability to lower LDL cholesterol. This was attributed to the nuts' fatty acid profile high in MUFA and their dietary fiber content (Kris-Etherton et al., 2001).

Hazelnut composition and feed source viability

Hazelnuts (*Corylus avellana* L.) are a tree nut primarily produced in Turkey, Italy, Spain and the United States. They are noted for having a FA profile high in MUFA, mostly in the form of oleic acid (18:1), and lipid content comprising ~60% of the edible kernel (Parcerisa et al., 1998). Additionally, hazelnuts contain elevated levels of Vitamin E (α-tocopherol) and sterols essential to human health (Parcerisa et al., 1998). The hazelnut is a crop of particular interest as an option to improve meat quality and nutrition in Oregon. Common breeds and varieties of hazelnuts grown in Oregon include Barcelona, Daviana, Montebello, Butler, Ennis, Halls Giant, and Willamette (Parcerisa et al., 1998). Production of these hazelnut varieties in Oregon accounts for 3% of global production (tons) (Xu & Hanna, 2011) and 99% of the entire U.S. yield (Xu et al., 2012). This production equaled 36,000 tons with a value totaling $120,600,000 in 2014 (United States Department of Agriculture, National Agricultural Statistics Service).

A cull portion of the Oregon hazelnut yield each year (~1%) is deemed unfit for consumer sale and consumption (S. Schussman, personal communication, July 28, 2016), due to aesthetic or conformational characteristics, yet these nuts still contain the same nutritional composition as those destined for retail sale. The use of these cull hazelnut byproducts in livestock dietary rations offers a multitude of potential benefits. Hazelnuts present the opportunity to advantageously alter fatty acid composition, improve the nutritional profile, enhance meat quality and extend shelf-life by incorporating greater amounts of MUFA and antioxidants into muscle and adipose tissues of animals.

Proximate composition and amino acid profile of hazelnuts

Alasalvar and others (2003) detail the proximate composition and amino acid profile of hazelnuts. The authors found that the proximate composition (g/100 g) in edible hazelnut kernels are comprised of 61.21g fat, 15.3g protein, 17.30g carbohydrates, with smaller proportions of moisture (3.90g) and ash (2.24g) rounding out its composition. Hazelnuts have a reported caloric energy level of 631 kcal (per 100g). They are also a rich source of dietary fiber, consisting of 12.88g/100 g, with insoluble fiber (10.67g/100 g) comprising the majority and soluble fiber (2.21g/100g) making up the remainder. Hazelnuts also possess many essential and non-essential amino acids, predominately glutamic acid (3.13 g/100g), arginine (2.16 g/100g) and aspartic acid (1.52 g/100 g). Lesser concentrations of alanine, cysteine, glycine, histidine, isoleucine, leucine, lysine, methionine, hydroxyproline, phenylalanine, proline, serine, threonine, tyrosine, tryptophan and valine were detected (Alasalvar et al., 2003). Hazelnuts have also been shown to be ideal sources for daily requirements of K, P, Mg, Ca, Mn, Fe, Zn, Cu, Rb, Sr, Na, Cr, and Al, micronutrients essential to healthy human bodily function and maintenance. Hazelnuts offer 55, 94, and 70% of daily recommended values for P, Fe, and Mg, respectively, per 100 g of daily consumption (Cosmulescu, Botu, & Trandafir, 2013).

Fatty acid profile of hazelnuts

Maguire and others (2004) investigated fatty acid composition of hazelnuts and other commonly consumed nuts. Of the total lipid oil (% of total) extracted from hazelnut kernels, 79.6% was that of MUFA, namely in the form of oleic acid (18:1), which made up 79.3% of hazelnut FA composition. PUFAs constituted 10.9% of total fatty acids, while SFA accounted for 9.2%. Of the fat sources studied, only macadamia nuts (82.4%) contained higher levels of total MUFA. Furthermore, hazelnuts contain substantially less linoleic acid (10.39%) than other commonly consumed nut and legume sources such as peanuts, walnuts, and almonds (44.6, 57.46, and 21.52%, respectively) (Maguire et al., 2004). Parcerisa and others (1998)

found that Oregon-grown hazelnut varieties have greater total MUFA content of lipid fractions (relative percentage) derived from crushed kernels (79.6%) than varieties sourced from Spain and Turkey (78.8 and 75.6%, respectively). Only Italian-grown hazelnut varieties had higher total MUFA content (82.0%) than Oregon varieties. With respect to sterol content (mg/kg^{-1}), β-sitosterol made up the majority of sterols detected, followed by campesterol, Δ^5-avenasterol, and stigmasterol found in all hazelnut varieties, but no significant difference of concentrations existed between varieties and country of origin (Parcerisa et al., 1998). Plant-derived sterol inclusion in the diet is known to lower LDL cholesterol levels in humans and aid in the prevention of CVD (Gylling et al., 2014).

Antioxidants in hazelnuts

In addition to the hazelnut's favorable fatty acid profile, it also contains high concentrations of antioxidants and phenolic compounds, especially α-tocopherol (Vitamin E). Hazelnut oil samples extracted from kernels were analyzed for α-tocopherol concentration (μg/g oil) by Maguire and others (2004) were found to contain higher concentrations of α-tocopherol (310.19) than that of macadamias, peanuts, and walnuts (122.39, 87.99, and 20.69, respectively). Of the nut oils evaluated, only almonds (439.59) contained higher levels of α-tocopherol (Maguire et al., 2004). However, Monagas and others (2009) found that when evaluated for total polyphenols (mg of GAE/g of skin) and antioxidant capacity (mmol of TE/g of skin), roasted hazelnut skins had higher overall values (107 and 3.05, respectively) than roasted skins of peanuts (73.9 and 2.13, respectively) and almonds (22.8 and 1.07, respectively). These values are significant because they quantitatively express concentration of flavonoids (plant-derived antioxidants) present in the sources from which they're derived. These findings are of further importance given flavonoids have been shown to possess antioxidant, anticarcinogenic, cardioprotective, antimicrobial, and neuroprotective properties (Monagas et al., 2009). When evaluated for origin (Turkey, Spain, Italy and United States), there was no significant

difference regarding hazelnut α-tocopherol content (mg/kg^{-1}) in lipid fractions (Parcerisa et al., 1998).

Hazelnuts as a dietary livestock feed source

Researchers have sought to explore the overall nutritional composition and feasibility of utilizing hazelnut byproducts in livestock feeding programs. These byproducts are primarily derived from hazelnut kernels and shells after harvest and processing. Although the hazelnut kernel's composition has been extensively highlighted in this text, it accounts for less than 50% of overall hazelnut weight (Xu & Hanna, 2009), which has prompted researchers to investigate benefits and detriments of other hazelnut components. Xu and others (2012) explored the viability of hazelnut byproducts, namely the shells, by analyzing the nutritional composition and phenolic and antioxidant capacity of U.S. hazelnut cultivars. The authors found that hazelnut shells are a rich source of carbohydrates in the form of crude fiber, and high in phenolic and antioxidant compounds. On the other hand, the hazelnut shells examined contained elevated levels of tannins. Total phenolic content (TPC) in Oregon-derived shells was comprised of 36-54% tannins (Xu et al., 2012). The presence of high concentrations of tannins may limit hazelnut shell use in livestock diets. This is due to tannins' antinutritional factors which affect nutrient (namely protein) utilization, potentially causing toxicity and death in livestock, although ruminants are more at risk than non-ruminants (Makkar, 2003). Moreover, pigs have been shown to use salivary and gastric mucin proline protein to bind high concentrations of tannins incorporated through the diet as a protective mechanism against tannin toxicity (Cappai et al., 2013).

It has been shown that supplementing livestock diets with hazelnut derivatives can yield positive benefits to livestock. Lambs fed a total mixed ration (TMR) supplemented with 3% hazelnut oil did not experience compromised effects to carcass finishing characteristics, blood parameters, bone weight, bone ash, or rumen microbial activity compared to control lambs fed the same TMR without supplementation. Additionally, 3% dietary hazelnut supplementation in the lamb's

diet resulted in a marked decrease in blood malondialdehyde (MDA) concentration and total cholesterol compared to control lambs (Cetingul et al., 2009).

Hazelnut effect on meat quality

Other studies that have examined the effects that hazelnut byproducts have on meat quality and sensory traits suggest potential benefits. The use of pre-emulsified hazelnut oil as a beef fat replacement in Turkish sucuk sausages by Yildiz-Turp and Serdaroğlu (2008) was shown to have positive effects on the nutritional value, shelf-life, and sensory traits of sausages tested. Cured and fermented beef sausages (20% total fat) were formulated with 15, 30, or 50% pre-emulsified hazelnut oil (mixed with whey protein), respectively, to replace beef fat, with no hazelnut oil inclusion serving as the control. The authors found that total cholesterol of sausages decreased significantly as hazelnut oil inclusion increased. The increase in MUFA and PUFA in treatment sausages did not adversely affect lipid oxidation measured in MDA concentration, as all treatment values were within the acceptable range (<0.1 malondialdehyde/kg). Additionally, no major difference in sensory trait acceptability scores was detected between treatments and control, although 15% hazelnut oil inclusion yielded the highest overall sensory acceptability score compared to control and 30 and 50% treatments (Yildiz-Turp and Serdaroğlu, 2008).

Turhan and others (2005) evaluated the effect that hazelnut pellicles, a byproduct of the roasting process, had on low-fat beef burgers when used as a fiber source. Ground hazelnut pellicles were incorporated into ground beef patties (10% fat) at 1, 2, 3, 4, and 5% by weight (50g portions), respectively, with no pellicle inclusion patties (20% fat) serving as the control. The authors reported significantly less cook loss % in pellicle-added patties compared to control, as well as a significant reduction in diameter and thickness of control patties vs. pellicle. This is likely attributed to the pronounced loss of fat and moisture during the cooking process in control patties. When evaluated for sensory traits (appearance, juiciness, flavor, and overall acceptability), overall acceptability decreased significantly as pellicle %

increased compared to control, however 1 and 2% hazelnut pellicle addition were deemed to be acceptable (Turhan, Sagir, & Ustun, 2005).

Although the current scope of knowledge is limited, the successful use of hazelnut byproducts in livestock diets and their ability to improve the nutritional composition and enhance meat quality and shelf-life attributes in previous studies presents the opportunity to explore their use further. Presently, little research has been conducted evaluating the impact hazelnut inclusion as a lipid source has on not only live animal performance, but also on the role it plays in altering fatty acid composition, meat quality, shelf-life and sensory attributes of meat products. Given that Oregon holds a comparative advantage in U.S. hazelnut production compared to other states, and that a cull segment of the hazelnut yield (~1%) is not presently utilized for human consumption, there may be opportunities for its use in feeding programs for non-ruminants. As previously mentioned, since non-ruminants have a propensity to more readily deposit constituents of their diets into muscle and fat tissues, along with the ability to better cope with antinutritional components such as tannins, they are ideal candidates for such feeding programs. Acorn-fed hog trials examining effects on meat quality and shelf-life lends validity to the premise that hazelnuts- which have similar fatty acid and antioxidant profiles as their acorn counterparts- can impart the same attributes with respect to pork products. Therefore, further research is warranted to explore the effects dietary hazelnut inclusion can have on these endpoints. To that end, the purpose of this study was to explore the effects of differing concentrations of cull hazelnuts as a lipid source in hog finishing rations, and their influence on pork shelf-life and fatty acid composition. We examined the hypothesis that hazelnut inclusion in hog diets would increase the ratio of MUFA to PUFA in pork fatty acid composition, increase shelf-life with respect to color stability and purge loss in pork products, and that sensory factors with respect to lipid oxidation would be retained in pork products during retail display.

3. MATERIALS AND METHODS

Diets

Raw (unroasted) cull hazelnuts (95% kernel/5% shell) were procured and stored in a bulk storage container at the Department of Animal and Rangeland Science's Poultry Center in Corvallis, OR. Cull hazelnuts were ground (<1mm diameter) every 7d (~45 Kg/week; to minimize lipid oxidation) throughout the duration of the feed trial (42d) using a hammer mill grinder (Southern Equipment Company, Goodlettsville, TN). Ground hazelnuts were used to replace 0, 15, or 30%, by weight, of a commercially-sourced hog finishing ration. Diets were designated as either H0 (control), H15 (15% hazelnut by weight), or H30 (30% hazelnut by weight).

Proximate composition and amino acid profile

Table 1 gives proximate composition of ground hazelnuts, base ration (H0) and mixed treatment rations (H15 and H30). Samples were analyzed by a commercial laboratory (Dairy One, Inc., Ithaca, NY) for moisture, dry matter, crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), crude fat, total digestible nutrients (TDN), net energy-lactation (NEL), net energy-maintenance (NEM), net energy-gain (NEG), Ca, P, Mg, K, Na, Fe, Zn, Cu, Mn, Mb, digestible energy (DE) and metabolizable energy (ME).

Amino acid profiles of ground hazelnuts, base ration (H0) and mixed treatment ration (H15 and H30) are presented in Table 2. Samples were analyzed by a commercial laboratory for aspartic acid, threonine, glutamic acid, proline, glycine, alanine, cysteine, valine, methionine, isoleucine, leucine and lysine (AOAC, 2016; method 994.12).

Table 1. Composition of animal diets and ground hazelnuts.

	Basal	15% Hazelnut	30% Hazelnut	Hazelnut
Moisture	10.4	9.8	8.7	7.0
Dry matter	89.7	90.2	91.3	93.0
CP	16.9	16.3	18.6	17.0
ADF	7.0	12.5	9.6	9.9
NDF	15.9	18.9	20.3	13.6
Fat	6.0	11.4	15.4	49.2
TDN, %	75	81	87	133
NEL Mcal/Kg	0.81	0.91	1.00	1.70
NEM Mcal/Kg	0.86	0.90	1.07	1.89
NEG Mcal/Kg	0.58	0.68	0.76	1.39
Ca,%	0.52	0.51	0.42	0.13
P, %	0.65	0.60	0.57	0.31
Mg, %	0.19	0.18	0.19	0.16
K, %	0.70	0.72	0.74	0.84
Na, %	0.142	0.127	0.106	0.004
Fe, ppm	252	237	210	89
Zn, ppm	144	130	110	27
Cu, ppm	25	19	18	13
Mn, ppm	55	56	50	37
Mb, ppm	1.2	0.9	0.9	ND
DE, Mcal/Kg	1.71	1.83	1.94	2.83
ME, Mcal/Kg	1.53	1.67	1.79	2.76
Phenols, GAE/g	1023.54	956.58	849.17	826.86
Vitamin E, mg/kg	30.34	-	-	74.02

Table 2. Amino acid composition (% w/w) of animal diets and ground hazelnuts.

	Basal	15% Hazelnut	30% Hazelnut	Hazelnut
Aspartic acid	1.41	1.43	1.54	1.67
Threonine	0.55	0.55	0.57	0.52
Glutamic acid	2.79	2.86	3.08	3.30
Proline	0.97	0.94	0.88	0.56
Glycine	0.66	0.68	0.72	0.75
Alanine	0.84	0.84	0.84	0.75
Cysteine	0.29	0.29	0.30	0.30
Valine	0.75	0.76	0.79	0.79
Methionine	0.26	0.27	0.26	0.23
Isoleucine	0.59	0.59	0.62	0.60
Leucine	1.38	1.36	1.37	1.14
Lysine	0.88	0.81	0.83	0.53

Fatty acid composition

Fatty acid composition of ground hazelnuts, base ration (H0) and mixed treatment rations (H15 and H30) were determined by extracting lipids using the method outlined by Folch and others (1957) and methylated using boron trifluoride methanol for Fatty Acid Methyl Esters (FAME) preparation. Ground hazelnuts and mixed treatment rations (1 g each) were extracted with 2:1 chloroform:methanol overnight before being mixed with 0.88% sodium chloride solution and centrifuged. The chloroform layer (lipid extract) was evaporated under nitrogen and the remaining lipids were mixed with 2 ml boron trifluoride in a boiling water bath for 60 minutes to methylate fatty acids. After cooling to room temperature, 2 ml hexane and 2 ml distilled water were mixed with the sample. Tubes were mixed by inversion and the hexane layer was saved for analysis by a gas chromatograph. Methylated lipids were analyzed via gas chromatograph with auto-sampler (Agilent HP 6890, Santa Clara, CA), flame ionization detector and SP-2330 fused capillary column (30 mm x 0.25 mm i.d.) (Agilent Technologies Inc., Santa Clara, CA). As described by Cherian, Bautista-Ortega and Goeger (2009), samples (1 ml) were injected with helium as the carrier gas onto the column programmed for increased oven temperatures (initial temperature was 110 ˚C, held for 1 min, then increased at 15 ˚C/min to 190 ˚C and held for 55 min, then increased at 5 ˚C/min to 230 ˚C and held for 5 min. Inlet and detector temperatures were both 220 ˚C. Fatty acid methyl esters were determined by comparison with retention times of authentic standards (Nuchek Prep, Elysian, MN). Peak areas and percentages were calculated using Hewlett Packard ChemStation software (Agilent Technologies Inc, Wilmington, DE). Fatty acid values were identified a relative percent of total identified fatty acids.

Vitamin E

Samples of feed (1 g) from ground hazelnuts and control diet (H0) were extracted using the method described by Podda and others (1996), and are reported in Table 1. Samples were mixed with 1.5 ml saturated potassium hydroxide, 5 ml water

with 1% ascorbic acid and 10 ml ethanol and incubated at 70 °C for 30 minutes. After cooling to room temperature, 25 µl of 1 mg/ml BHT, 5 ml 1% ascorbic acid and 10 ml hexane were added. A phase separation was allowed to occur and 5 ml of the hexane layer was removed and evaporated to dryness under nitrogen. The sample was reconstituted with 1:1 ethanol:methanol before separation by HPLC. Fluorescence detection was performed using the method described by Pinheiro-Sant'Ana et al. (2011). A Shimadzu Prominence UFLC (Shimadzu USA MFG, INC) with fluorescence detection was used to quantify Vitamin E as α-tocopherol. Excitation and emission wavelengths were 295 and 325 nm, respectively. Resulting values were compared to a standard curve from an α-tocopherol standard and quantified. Values were reported as IU/kg.

Phenols

Total phenols in ground hazelnuts and dietary rations (H0, H15 and H3) are reported in Table 1. Samples were measured by the Folin-Ciocalteau colorimetric method and extracted as described by Aziza, Quezada and Cherian (2010). Samples were extracted in 80% methanol in a shaking water bath at 75 °C for 1 hour. Extracts were centrifuged at 3,000xg for 15 minutes, then filtered. An aliquot (200 µl) of the filtered extract was added to 200 µl of 2:1 methanol:water, 800 µl of 7.5% sodium bicarbonate and 1 ml of 10% Folin-Ciocalteau reagent. After 30 minutes, the absorbance of the reaction mixture was read on a UV-Vis spectrophotometer (Shimadzu UV-2400, Shimadzu Scientific Instruments, Inc, Columbia, MD, USA) at 765 nm. The resulting value was compared to a standard curve built using gallic acid and reported as gallic acid equivalents (GAE)/g sample.

Animals

Berkshire-cross hogs (n=15, 7 barrows, 8 gilts, avg. 97 Kg) were obtained and housed at the Department of Animal and Rangeland Sciences' Swine Center in Corvallis, OR, in accordance with Oregon State University's Institutional Animal

Care and Use Committee (ACUP 4619). Hogs were housed in individual pens, and underwent a 7 day acclimation period in which they were fed a commercially available premixed hog ration (GroLean Grower 50-140, CHS Nutrition, Inver Grove Heights, MN) which contained ground corn, soybean, wheat middlings, dried distillers grain, dicalcium phosphate (21%), soy oil, calcium carbonate, salt, lysine (80%), CHS swine VIT, CHS swine TM, Allzyme SSF and Meth DL-98 in unspecified amounts. The chemical, nutrient and mineral composition is given in Tables 1 and 2. After day 7 of the acclimation period, hogs (5/diet) were stratified by sex and weight, assigned to one of three treatment groups (H0, H15, or H30) and fed *ad libitum*, individually, for 42d to achieve standard commercial finishing weights. Hogs had free access to fresh water from nipple drinker in each pen.

On day 42, hogs were transported to the Clark Meat Science Center at Oregon State University. Hogs were electrically stunned in accordance with the Humane Slaughter Act, exsanguinated, and dressed to industry-accepted procedures under USDA-FSIS inspection. Carcasses were weighed prior to chilling and hot carcass weights were recorded. Carcasses chilled at 3˚C±1 for 72h.

Sample collection and analysis

Live animal performance and carcass characteristics

Hog live weights were recorded upon arrival at facility, and once a week for 42d during feed trial using a scale (58SX, W-W Paul Scales, Duncan, OK).

Carcasses were chilled for 72h post-mortem at 3˚C±1. After 72h, carcasses were ribbed between the 10^{th} and 11^{th} rib. Backfat thickness measurements were taken off the midline at a point three-fourths of the width of the *Longissimus* muscle from the medial side of the carcass between the 10^{th} and 11^{th} rib (Aberle, 2001) using a backfat probe, and the loin eye area (cm^2) was determined using a grid. Subjective loin eye color and marbling scores were evaluated using National Pork Producers Council (NPPC, 1999) color and marbling photo standards to determine quality grade. To determine pH, a probe attached to a pH meter (Model HI 99163, Hanna

Instruments Inc., Woonsocket, RI) was inserted into the loin and two readings were taken for each experimental unit.

Sample packaging

The *Longissimus* from one side of each carcass was excised 72h post-mortem, trimmed as loins, packaged in impermeable vacuum pouches (Clarity™ 3-Mil nylon, Bunzl Processor Division, Kansas City, MO) and vacuum-sealed using a single chamber packaging machine (Model SC-680, Promarks Inc. Ontario, CA). Loins were stored at 3˚C±1 for 4d in the dark to simulate transportation. At the conclusion of storage, loins were removed from packaging and sliced into 2.54 cm chops for retail shelf-life analyses using a deli slicer (Model GSP-V, Bizerba GmbH & Co, Balingen, Germany).

Chops were weighed and placed in 21 x 14.6 x 1.9 cm black polystyrene trays (CKF Inc., Langley, B.C., Canada) with a soaker pad (Dri-loc AC-25, Sealed Air-Cryovac, Duncan, SC) in each tray, and overwrapped using a Heat Sealing Co. PVC overwrap machine (Model 625, Heat Sealing Mfg. Co., Cleveland, OH) with clear stretch O_2 permeable film (RMF 61-HY). The overwrap film had an O_2 transmission rate of 217 $cm^3/1\ m^2$ per 24 hr at 23 °C.

pH and proximate composition

Muscle samples derived from intact loins from carcasses of H0, H15, and H30 mixed diets were analyzed for proximate composition (fat, moisture). Samples were frozen in liquid nitrogen and pulverized in a Waring blender into a fine powder. Pulverized samples were placed in Whirlpak® bags and stored at -20 ˚C until analyzed for proximate composition. Moisture (AOAC, 2016; method 950.46) was determined by air drying, and crude fat (AOAC, 2016; method 960.39) was determined via ether extraction. To determine loin pH, 10 g of powder was mixed with 90 ml of deionized distilled water. The pH of the solution was measured by

inserting a probe attached to a pH meter (Model pH 3210, WTW GmbH, Weilheim, Germany) and two readings were taken for each experimental unit.

Fatty acid analysis

Lean tissue and adipose samples were collected from intact loins from carcasses of H0, H15, and H30 mixed diets. Samples were frozen in liquid nitrogen and pulverized in a Waring blender into a fine powder. Pulverized samples were placed in Whirlpak® bags and stored at -20 ˚C until they were evaluated for fatty acid composition. Lipids were extracted using the method outlined by Folch and others (1957) and methylated using boron trifluoride methanol for Fatty Acid Methyl Esters (FAME) preparation. Muscle and adipose tissue samples (1 g each) were extracted with 2:1 chloroform:methanol overnight before being mixed with 0.88% sodium chloride solution and centrifuged. The chloroform layer (lipid extract) was evaporated under nitrogen and the remaining lipids were mixed with 2 ml boron trifluoride in a boiling water bath for 60 minutes to methylate fatty acids. After cooling to room temperature, 2 ml hexane and 2 ml distilled water were mixed with the sample. Tubes were mixed by inversion and the hexane layer was saved for analysis by a gas chromatograph. Methylated lipids were analyzed via gas chromatograph with auto-sampler (Agilent HP 6890, Santa Clara, CA), flame ionization detector and SP-2330 fused capillary column (30 mm x 0.25 mm i.d.) (Agilent Technologies Inc., Santa Clara, CA). As described by Cherian, Bautista-Ortega and Goeger (2009), samples (1 ml) were injected with helium as the carrier gas onto the column programmed for increased oven temperatures (initial temperature was 110 ˚C, held for 1 min, again increased at 15 ˚C/min to 190 ˚C and held for 55 min, then increased at 5 ˚C/min to 230 ˚C and held for 5 min. Inlet and detector temperatures were both 220 ˚C. Fatty acid methyl esters were determined by comparison with retention times of authentic standards (Nuchek Prep, Elysian, MN). Peak areas and percentages were calculated using Hewlett Packard ChemStation

software (Agilent Technologies Inc, Wilmington, DE). Fatty acid values were identified by weight percent of total fatty acid.

Vitamin E

Lean tissue samples were collected from intact loins from carcasses of H0, H15, and H30 mixed diets. Samples were frozen in liquid nitrogen and pulverized in a Waring blender into a fine powder. Pulverized samples were placed in Whirlpak® bags and stored at -20 ˚C until they were evaluated for vitamin E content. Muscle samples (1 g) from loins were extracted using the method described by Podda and others (1996). Samples were mixed with 1.5 ml saturated potassium hydroxide, 5 ml water with 1% ascorbic acid and 10 ml ethanol and incubated at 70 °C for 30 minutes. After cooling to room temperature, 25 µl of 1 mg/ml BHT, 5 ml 1% ascorbic acid and 10 ml hexane were added. A phase separation was allowed to occur and 5 ml of the hexane layer was removed and evaporated to dryness under nitrogen. The sample was reconstituted with 1:1 ethanol:methanol before separation by HPLC. Fluorescence detection was performed using the method described by Pinheiro-Sant'Ana et al. (2011). A Shimadzu Prominence UFLC (Shimadzu USA MFG, INC) with fluorescence detection was used to quantify Vitamin E as α-tocopherol. Excitation and emission wavelengths were 295 and 325 nm, respectively. Resulting values were compared to a standard curve from an α-tocopherol standard and quantified. Values were reported as IU/kg.

Phenols

Lean tissue and adipose samples were collected from intact loins from carcasses of H0, H15, and H30 mixed diets. Samples were frozen in liquid nitrogen and pulverized in a Waring blender into a fine powder. Pulverized samples were placed in Whirlpak® bags and stored at -20 ˚C until they were evaluated for total phenolic content. Total phenols in muscle and adipose tissue were measured by the Folin-Ciocalteau colorimetric method and extracted as described by Aziza, Quezada

and Cherian (2010). Samples were extracted in 80% methanol in a shaking water bath at 75 °C for 20 minutes. Extracts were centrifuged at 3,000xg for 15 minutes, then filtered. An aliquot (200 µl) of the filtered extract was added to 200 µl of 2:1 methanol:water, 800 µl of 7.5% sodium bicarbonate and 1 ml of 10% Folin-Ciocalteau reagent. After 30 minutes, the absorbance of the reaction mixture was read on a UV-Vis spectrophotometer (Shimadzu UV-2400, Shimadzu Scientific Instruments, Inc, Columbia, MD, USA) at 765 nm. The resulting value was compared to a standard curve built using gallic acid and reported as gallic acid equivalents (GAE)/g sample.

Shelf-life sampling

Chops were stored in walk-in cooler at 3˚C±1, randomly assigned to retail shelving units, and subjected to continuous fluorescent lighting (3500K CCT, 1600-2200 lux) (AMSA, 2012).

Chops were measured for instrumental color every 24h for 10d using a HunterLab MiniScan EZ portable spectrophotometer (Model 45/0 LAV, Hunter Associates Laboratory, Inc. Reston, VA) with a 1.54 cm aperture, calibrated with black and white standards. CIE *L**, *a**, and *b** color space values were calculated (CIE, 1978). Chops were moved and rearranged at random on retail shelving units after each day's instrumental color evaluation to account for variations in fluorescent lighting intensity at different locations on shelving units.

At 0, 2, 4, 6d whole chops were removed from retail display simulation to determine purge loss. Purge loss denotes the fluid lost from each loin chop during retail display. The calculation for purge loss is given as $\text{Purge}(\%) = (S_0\text{-}S_1)/S_0 \times 100$, where S_0 signifies the weight of the chop at slicing and S_1 denotes the weight of the chop after removal from retail display. Chops were weighed using a digital scale (Model SP6001, OHAUS Corporation, Parsippany, NJ).

At 0, 2, 4, 6, and 10d whole chops were removed from retail display and 2 mm thick slices were taken from the exposed surface (display face) of a chop from each treatment using a deli slicer (Model GSP-V, Bizerba GmbH & Co, Balingen,

Germany). Samples were frozen in liquid nitrogen and pulverized in a Waring blender into a fine powder. Pulverized samples were placed in Whirlpak® bags and stored at -20 ˚C until they were analyzed for lipid oxidation. Lipid oxidation was determined using the 2-thiobarbituric acid reactive substances (TBARS) method of Buege and Aust (1978) with minor modifications. Briefly, 10 g of sample were homogenized in 3 volumes of distilled water and centrifuged at 3000*g* for 10 min at 4 °C. Supernatant (2 mL) was mixed with 4 mL 15% trichloroacetic acid/20 mM thiobarbituric acid and 100 μL 10% butylated hydroxyanisole and vortexed meticulously before being placed in a boiling water bath for 15 min. Subsequently, samples were cooled in an ice water bath for 10 min, and again vortexed and centrifuged as described above. Absorbance of the supernatant was read on a spectrophotometer (Shimadzu UV-2400, Shimadzu Scientific Instruments, Inc, Columbia, MD, USA) at 532 nm and compared to a malondialdehyde standard constructed using 1,1,3,3 tetra-ethoxypropane. Results are reported as mg malondialdehyde/kg of meat.

Statistical analysis

The study was structured as a completely randomized design, with the animal serving as the experimental unit and a random effect. Animals were assigned to treatment groups to yield similar average weights and similar numbers of males and females. Data were analyzed using a Mixed Model in the JMP software package (Version 11.3, SAS Institute, Cary, NC). Shelf-life data used day of display as a repeated measure. The main effect of diet treatment was submitted to analysis of variance (ANOVA). For shelf-life data, the repeated effect of day of display was added to the model, and the two-way interaction between diet treatment and day of display was also investigated with ANOVA. Means were separated, where appropriate, using Tukey's Honestly Significant Difference (HSD) to protect the experiment wise Type I error rate. In the case of a two-way interaction (TBARS), effect slices to test model significance within across treatments within day of display were used rather than

separating all mean; this technique was also used to protect experiment wise Type I error rate. Significance level was set to $P<0.05$. Four animals were determined to have pale, soft and exudative (PSE) meat upon fabrication, and were excluded from color and purge analyses, leaving replication at 3 for H0, 3 for H30, and 5 for H15.

4. RESULTS AND DISCUSSION

Live animal performance

Weekly least square means for hog weight gain and finishing weights are presented in Figure 7. Treatment x week interaction did not have a significant impact on hog weights (P=0.256). H0 hogs had an overall higher numerical mean finishing weight (134.8 Kg) than treatment H15 (127.1 Kg) and H30 (128.4 Kg) hogs. However, main effect on finishing weight did not differ significantly between treatments (P=0.798). These findings are similar to those reported by Daza, Menoyo and López-Bote (2010), where pigs fed a formulated diet experienced greater slaughter and carcass weights than pigs fed an acorn diet. As hazelnut inclusion rose in diets, DE and ME energy increased, however protein level did not appreciably increase with hazelnut inclusion. This effect is likely due to hazelnut rations containing approximately the same protein content as control diet, yet substantially higher fat content as reported in Tables 1 and 2.

Additionally, Teye and others (2006) found that finishing hogs fed a low lysine diet (7 g/kg feed) had significantly lower daily weight gain and feed conversion efficiency than hogs fed a high lysine diet (10 g/kg feed), with both groups being fed the same amount of digestible energy (14 MJ). However, final live and hot carcass weights did not differ significantly between hogs fed either a low or high lysine diet (Teye et al., 2006). These findings may explain how lower lysine content could have potentially inhibited overall weight gain in hazelnut-fed hogs compared to control hogs in this study, as H0 diets contained higher numerical levels of lysine (0.88 % w/w) compared to H15 and H30 rations (0.81 and 0.83 % w/w, respectively). Future studies and livestock producers seeking to employ hazelnuts' compositional qualities in livestock diets must account for these effects regarding protein and energy content when formulating dietary rations.

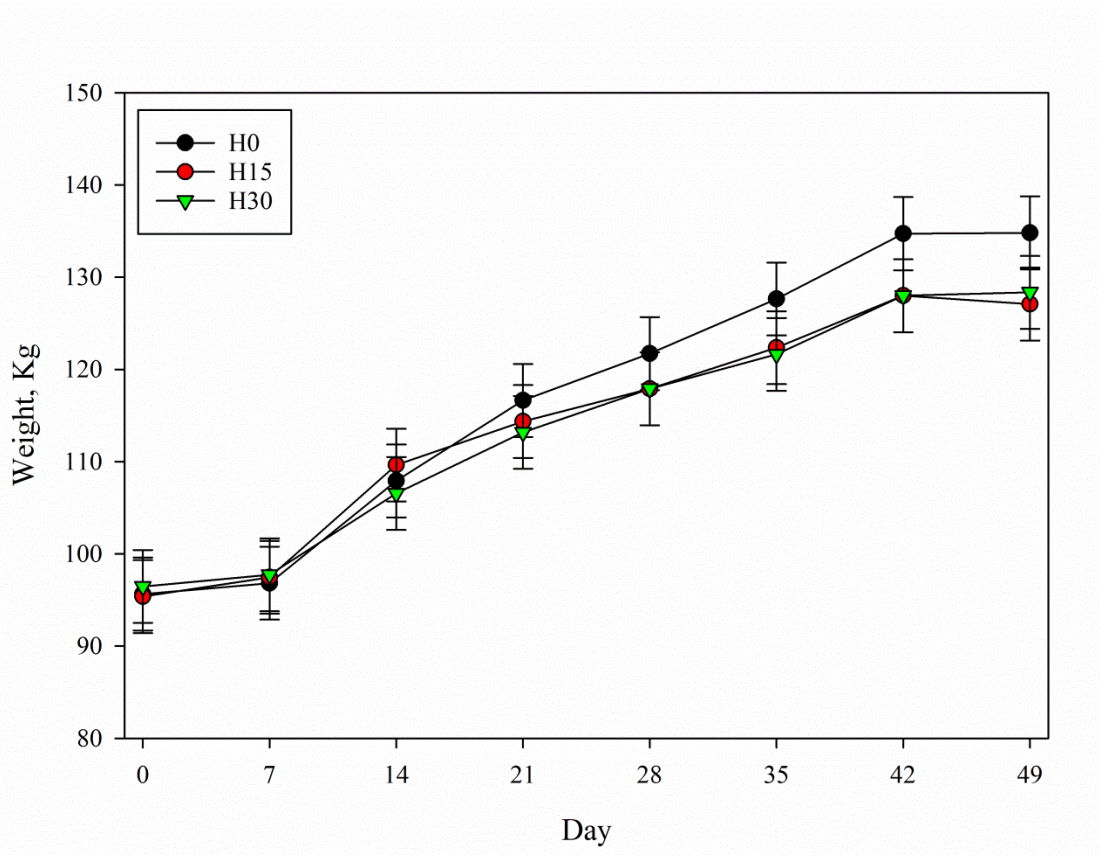

Figure 7. Weekly least square means for hog weight gain and finishing weights (Kg).

Carcass characteristics

Carcass characteristics measured in the study are presented in Table 3. Hot carcass weight (HCW) was highest in H0 hogs (103.09 Kg), yet did not differ significantly (P>0.05) between H15 (95.95 Kg) and H30 (98.73 Kg) hogs. Dressing percentage was also not affected by diet treatment (P>0.05). Rey and others (2006) found significantly lower HCW values in hogs fed extensively on acorns and grass than hogs fed a formulated diet. Although the differences in HCW did not differ significantly in this study, the higher numerical values in HCW of control (H0) hogs could be explained by the lower protein/total energy ratio in treatment (H15 and H30) hog diets, as previously mentioned.

Backfat thickness did not differ significantly between H0, H15 and H30 groups (P>0.05), nor did marbling (P>0.05), subjective color evaluation (P>0.05) and loin eye area (P>0.05), although H0 hogs experienced higher numerical mean loin eye area (49.68 cm^2) than H15 (43.35 cm^2) and H30 (43.74 cm^2) treatment hogs. *Longissimus* muscle from ribbed carcasses measured for L^*, a^* and b^* instrumental color scores 72h post-mortem did not experience any significant differences based on diet treatment (P>0.05).

Proximate composition and pH

Table 4 shows proximate composition (moisture and fat percentage) and pH of intramuscular samples sourced from *Longissimus* of each diet treatment (H0, H15, H30). No statistical difference was detected for moisture and fat percentages or pH (P>0.05) based on diet treatment. These results are similar to those reported by Phillips et al. (2001) in which pork samples from hogs fed either a control diet or a diet supplemented with 170 mg α-tocopherol acetate/kg feed experienced no significant differences in moisture and fat in Boston butt, or *Longissimus* pH.

Table 3. Carcass characteristics from hogs fed diets without (H0) or with 15 (H15) or 30% (H30) cull hazelnuts in the diet.

	H0	H15	H30	SEM[a]
Hot carcass weight, Kg	103.09	95.95	98.73	3.69
Dressing %	78.13	76.90	78.64	0.62
Back fat thickness, cm	2.90	2.49	2.64	0.40
Loin eye area, cm^2	49.68	43.35	43.74	3.25
Marbling[b]	1.20	1.80	1.40	0.28
Color score[c]	2.00	2.00	2.20	0.12
pH	5.43	5.55	5.54	0.04
*L**	66.64	64.16	64.17	1.52
*a**	19.90	20.92	20.27	0.44
*b**	19.99	20.13	19.68	0.41

Means with differing superscripts are significantly different ($P<0.05$)
[a]Standard error of the mean
[b]Marbling scored on a 1-10 scale according to the National Pork Board guidelines
[c]Color scored on a 1-6 scale according to National Pork Board guidelines

Table 4. Proximate composition of intramuscular samples derived from *Longissimus* of hogs fed diets without (H0) or with 15 (H15) or 30% (H30) cull hazelnuts in the diet.

	H0	H15	H30	SEM[a]
Moisture %	70.18	70.54	68.57	0.87
Fat %	5.16	4.66	7.35	1.26
pH	5.37	5.48	5.42	0.06

Means with differing superscripts are significantly different ($P<0.05$)
[a]Standard error of the mean

Fatty acid composition

Dietary feed rations and cull hazelnuts

Relative percentages of fatty acids in feed rations from control (H0), H15, H30 and cull hazelnuts are presented in Table 5. As expected, H30 feed rations contained highest overall 18:1 content (70.3%), followed by H15 (58.6%) and control diet (34.6%). H30 also contained a higher overall MUFA content (70.6%) compared to H15 and control diets (58.9 and 34.7%, respectively). Total SFA was highest in H0 feed rations (16.0%) and experienced a decrease in relative percentages as hazelnut inclusion increased in H15 and H30 rations (11.5 and 7.3%, respectively). Overall PUFA concentration also decreased as higher percentages of hazelnuts were added to diet treatments, with H0 diets containing highest total PUFA (49.2%), followed by decreasing percentages in H15 (29.7%) and H30 (22.2%) rations. H30 MUFA, SFA and PUFA relative fatty acid percentages were similar in composition to acorns used in an Iberian dietary treatment reported by Pérez-Palacios and others (2009). The increase in MUFA and decrease in PUFA through hazelnut inclusion is likely attributed to PUFA content in the corn and soybean constituents that largely comprised the commercial ration used in this study. Through hazelnut incorporation in H15 and H30 diets, MUFA content found within hazelnuts replaced PUFA content derived from corn and soybean meal.

Palmitic (16:0), stearic (18:0), linoleic (18:2) and α-linolenic (18:3n-3) acids all decreased numerically as dietary hazelnut concentration increased (15 and 30%) compared to commercial diet (H0). MUFA/PUFA and n-6/n-3 ratios both increased numerically through increased dietary hazelnut inclusion. Fatty acid relative percentages of cull hazelnuts used in H15 and H30 diets were comprised of 73.5% MUFA (73.1% oleic acid), 18.0% PUFA (17.6% linoleic acid) and 8.5% SFA (5.8 and 2.0% palmitic and stearic acid, respectively). MUFA relative percentages for hazelnuts used in this study were lower than those previously reported by Maguire and others (2004) and Parcerisa and others (1998) (79.6 and 79.6%, respectively), however the authors in those studies only analyzed hazelnut kernels. Ground

hazelnuts used in this study were a mix of shells (~5%) and kernels (~95%), which likely accounted for the lower total MUFA content compared to whole kernel lipid extracts evaluated in other studies.

Longissimus muscle tissue

Relative percentages of fatty acids in pork *Longissimus* muscle between H0, H15 and H30 treatments are presented in Table 6. As expected, oleic acid (18:1) concentration increased in muscle samples through hazelnut inclusion in diets. Samples from H30 treatment experienced highest relative percentage of 18:1 (49.0%) compared to H15 (46.8%) and H0 (43.3%), and both H15 and H30 18:1 concentrations were significantly higher than control ($P<0.05$) samples. Both H15 (50.1%) and H30 (52.2%) contained significantly higher total MUFA content ($P<0.05$) in samples than H0 (46.5%). Higher MUFA and 18:1 concentrations in muscle samples from Iberian hogs fed acorn and grass diets compared to samples from hogs finished intensively on mixed concentrate rations have been noted by previous authors (Cava et al., 1997; Andrés et al., 2001; Tejerina et al., 2012). The acorns used in the aforementioned Iberian studies incorporated higher levels of MUFA in hog diets compared to hogs finished on intensive, indoor feeding regimes that were comprised primarily of corn and soya meal.

Palmitic acid (16:0) content in muscle also decreased as hazelnut inclusion increased in diets, as H0 samples (23.6%) contained higher percentages than H15 (22.8%) and H30 (21.3%) treatments, with H30 samples containing significantly lower concentrations of 16:0 ($P<0.05$) than H0 samples. Myristic (14:0) and stearic acid (18:0) percentages also decreased in *Longissimus* samples as hazelnut inclusion increased. H30 samples contained significantly less ($P<0.05$) 14:0 and 18:0 than H0 samples. H15 and H30 total SFA (38.1 and 34.7%, respectively) were significantly less ($P<0.05$) than control samples (40.9). Previous studies have observed significant decreases in total SFA content in pork muscle samples as MUFA concentration increased in dietary hog rations (Rhee et al., 1990; Cava et al., 1997; Andrés et al.,

2001, Tejerina et al., 2012). As stated previously, the intent of these Iberian studies was to incorporate larger percentages of MUFA in pork tissues through dietary acorn inclusion, compared to control hogs fed on intensive, mixed concentrate rations consisting of corn and soybean meal, which are substantially higher in 16:0 and 18:2 fatty acids than acorns. This is in turn had a profound effect on decreasing SFA content in pork muscle (Rhee et al., 1990; Cava et al., 1997; Andrés et al., 2001, Tejerina et al., 2012). The H0 diet used in this study also observed higher concentrations of 16:0 and overall SFA compared to H15 and H30 diets, as reported in Table 5.

Of the other fatty acids detected, there were no significant differences between diet treatment in muscle samples ($P>0.05$) in the following fatty acids: 16:1, 18:2, 18:3n-3, 20:0, 20:2, and 20:4. Linoleic (18:2) fatty acids did not differ significantly between diet treatments, and H30 experienced the highest numerical percentage (10.7%) of 18:2 compared to H0 (10.0%) and H15 (9.2%) samples. The findings regarding linoleic acid (18:2) in *Longissimus* samples between control and treatment groups are surprising given the higher overall 18:2 content in control (H0) feed rations than in H15 and H30 (Table 5). The lack of significance in loin 18:2 concentrations between control (H0) and treatment (H15 and H30) groups may be attributed to the Berkshire breed used in this study, which are shown to inherently possess lower concentrations of linoleic acid in muscle and fat depots than other commonly used breeds. A study by Wood et al. (2004b) found that relative 18:2 fatty acid percentages in Berkshire *Longissimus dorsi* and *Psoas major* muscle samples were significantly lower than Duroc, Large White and Tamworth breeds from hogs fed the same commercial diet (barley, wheat, wheat-feed, soyabean meal and maize gluten). Total PUFA, n-6/n-3 ratio and MUFA/PUFA did not differ significantly ($P>0.05$) in samples based on diet treatment.

Table 5. Relative percentages of fatty acids in the control diet (H0), H15, H30 and cull hazelnuts.

Fatty acid	H0	H15	H30	Hazelnuts
14:0	0.3	0.3	0.1	0.3
16:0	12.3	8.3	6.8	5.8
16:1	0.2	0.2	0.3	0.4
18:0	2.9	2.4	ND	2.0
18:1 (all isomers)	34.6	58.6	70.3	73.1
18:2 (n-6)	45.6	28.1	21.2	17.6
18:3 (n–3)	3.6	1.6	0.9	0.2
20:0	0.3	0.2	0.2	0.1
20:2 (n-6)	ND	ND	0.1	0.2
20:4 (n-6)	ND	ND	ND	ND
n-6/n-3 ratio[a]	12.7	17.4	25.0	92.2
MUFA/PUFA ratio[b]	0.7	2.0	3.2	4.1
SFA[c]	16.0	11.5	7.3	8.5
MUFA[c]	34.7	58.9	70.6	73.5
PUFA[c]	49.2	29.7	22.2	18.0

[a]n-6/n-3 ratio = (18:2 + 20:2 + 20:4) / 18:3

[b]MUFA/PUFA ratio = (16:1 + 18:1) / (18:2 + 18:3 + 20:2 + 20:4)

[c]SFA = Saturated fatty acids (14:0 + 16:0 + 18:0 + 20:0) , MUFA = monounsaturated fatty acids (16:1 + 18:1), PUFA = polyunsaturated fatty acids (18:2 + 18:3 + 20:2 + 20:4)

Table 6. Relative percentages of fatty acids from pork *Longissimus* muscle from hogs fed control diets (H0) or diets containing 15 (H15), or 30% (H30) ground hazelnuts.

Fatty acid	H0	SEM[d]	H15	SEM[d]	H30	SEM[d]
14:0	2.4[a]	0.17	2.0[ab]	0.19	1.7[b]	0.17
16:0	23.6[a]	0.43	22.8[a]	0.49	21.3[b]	0.43
16:1	3.2	0.19	3.3	0.21	3.2	0.19
18:0	12.5[a]	0.49	11.4[ab]	0.55	10.2[b]	0.49
18:1 (all isomers)	43.3[b]	0.93	46.8[a]	1.04	49.0[a]	0.93
18:2 (n-6)	10.0	0.68	9.2	0.76	10.7	0.68
18:3 (n–3)	0.8	0.07	0.8	0.08	0.8	0.07
20:0	0.8	0.08	0.9	0.09	0.7	0.08
20:2 (n-6)	0.3	0.14	0.6	0.15	0.4	0.14
20:4 (n-6)	1.4	0.23	1.2	0.26	1.2	0.23
SFA[e]	40.9[a]	0.66	38.1[b]	0.74	34.7[c]	0.66
MUFA[e]	46.5[b]	0.98	50.1[a]	1.09	52.2[a]	0.98
PUFA[e]	12.6	0.99	11.8	1.11	13.1	0.99
n-6/n-3 ratio[f]	14.7	1.32	13.9	1.48	15.4	1.32
MUFA/PUFA ratio[g]	3.9	0.42	4.0	0.47	4.3	0.42

[a-c]Means with differing superscripts are significantly different ($P< 0.05$)
[d]Standard error of the least squared mean
[e]SFA = Saturated fatty acids (14:0 + 16:0 + 18:0 + 20:0) , MUFA = monounsaturated fatty acids (16:1 + 18:1), PUFA = polyunsaturated fatty acids (18:2 + 18:3 + 20:2 + 20:4)
[f]n-6/n-3 ratio = (18:2 + 20:2 + 20:4) / 18:3
[g]MUFA/PUFA ratio = (16:1 + 18:1) / (18:2 + 18:3 + 20:2 + 20:4)

Adipose tissue samples

Relative percentage of fatty acids from subcutaneous back-fat samples from hogs fed control (H0) rations, and 15 (H15) or 30% (H30) ground hazelnuts diets are presented in Table 7. Just as in *Longissimus* samples, 18:1 concentration in back-fat samples increased significantly ($P<0.05$) through hazelnut inclusion in the diets. H15 and H30 18:1 content (48.2 and 50.4%, respectively) was significantly greater ($P<0.05$) than in fat samples sourced from control hogs (43.7%). Relative percentages of 16:0 also decreased significantly ($P<0.05$) at the highest level of hazelnut inclusion, with H30 treatments experiencing lower percentages ($P<0.05$) of 16:0 (18.7%) than H0 (21.1%) samples. These findings are similar to those reported by Rey and others (2006) in which acorn-fed Iberian hogs experienced significantly higher proportions of oleic acid and lower proportions of palmitic acid in subcutaneous fat samples compared to hogs fed a formulated diet. Myristic acid (14:0) percentages in samples also decreased significantly ($P<0.05$) as hazelnut inclusion in diets increased, with H30 fat samples (1.4%) containing a lower percentage of 14:0 ($P<0.05$) than control (1.7%). Stearic acid (18:0) concentrations in H15 and H30 fat samples (10.0 and 9.8%, respectively) decreased significantly through hazelnut inclusion ($P<0.05$) compared to H0 samples (12.4%). There were no significant differences detected in 16:1, 18:2, 18:3n-3, 20:0, 20:2 and 20:4 in samples sourced from either control hogs or H15 and H30 diet treatments ($P>0.05$).

Total MUFA in fat samples analyzed differed significantly ($P<0.05$) between H0 hogs (45.9%) and H15 and H30 treatments (50.5 and 52.6%, respectively), as total MUFA in samples increased with an increase in dietary hazelnut inclusion. As in muscle samples analyzed for fatty acid percentages, SFA in back-fat decreased as hazelnut inclusion in hog diets increased. H15 and H30 samples (31.9 and 31.2%, respectively) had significantly lower percentages of total SFA ($P<0.05$) than control samples (36.7%). These findings regarding differences in total MUFA and SFA in fat samples are similar to those reported by Ruiz and others (1998) in samples from hogs raised in a *Montanera* feeding system versus those finished on a commercial ration. Total concentrations of PUFA and n-6/n-3 ratios in subcutaneous back-fat did not

differ significantly based on dietary treatment ($P>0.05$). The MUFA/PUFA ratio in H30 (3.2) was significantly higher ($P<0.05$) than H0 samples (2.6). The findings regarding MUFA/PUFA ratio in respective dietary treatment samples were expected given the elevated concentrations of MUFA in H15 and H30 rations compared to control (H0). Hazelnut inclusion's ability to positively impact MUFA and decrease SFA in subcutaneous fat suggests possible human health benefits regarding high MUFA intake and lower LDL cholesterol (Grundy, 1986; Assmann & Gotto, 2004; WHO, 2008; Rozati et al., 2015). Lower SFA content and the potential for lower LDL cholesterol may provide positive dietary health claims, especially in high-fat pork products such as sausages, frankfurters and bacon. Higher percentages of fat are typically present or are used in the manufacture of these products compared to leaner pork retail cuts, such as chops and roasts.

α-tocopherol and phenol content

Tables 8 and 9 show vitamin E (α-tocopherol) and total phenol content in intramuscular (IM) and adipose (AP) tissue from hogs fed a diet without (H0) ground hazelnuts or with ground hazelnuts added at 15 (H15) or 30% (H30) of the diet. Total phenols did not differ significantly in AP ($P>0.05$) or IM ($P>0.05$) samples based on diet treatment. Total phenols did increase numerically in IM samples as hazelnut inclusion increased in diet. H0 samples had lowest numeric total phenols (178.80 GAE/g) compared to H15 and H30 (182.00 and 201.96 GAE/g, respectively). Total phenols in AP samples were highest in H15 (103.78 GAE/g), followed by H30 (94.85 GAE/g) and H0 (89.95 GAE/g), however no significant difference ($P>0.05$) was detected in AP samples between diet treatments. As reported in Table 1, H0 diets contained higher numerical total phenols than H15 and H30 diets, which likely accounted for a lack of significant differences in samples.

Table 7. Relative percentage of fatty acids in subcutaneous back-fat from pork *Longissimus* muscle from hogs fed control diets (H0), or diets containing 15 (H15), or 30% (H30) ground hazelnuts.

Fatty acid	H0	H15	H30	SEM[c]
14:0	1.7[a]	1.5[ab]	1.4[b]	0.09
16:0	21.1[a]	19.1[ab]	18.7[b]	0.67
16:1	2.2	2.3	2.2	0.08
18:0	12.4[a]	10.0[b]	9.8[b]	0.67
18:1 (all isomers)	43.7[b]	48.2[a]	50.4[a]	0.89
18:2 (n-6)	14.9	15.2	14.2	0.75
18:3 (n–3)	1.5	1.4	1.1	0.08
20:0	0.8	0.8	0.7	0.05
20:2 (n-6)	0.6	0.6	0.5	0.04
20:4 (n-6)	0.5	0.5	0.4	0.03
SFA[d]	36.7[a]	31.9[b]	31.2[b]	1.31
MUFA[d]	45.9[b]	50.5[a]	52.6[a]	0.88
PUFA[d]	17.5	17.6	16.3	0.81
n-6/n-3 ratio[e]	11.1	11.9	13.5	0.82
MUFA/PUFA ratio[f]	2.6[b]	2.9[ab]	3.2[a]	0.14

[a,b]Means with differing superscripts are significantly different ($P< 0.05$)
[c]Standard error of the least squared mean
[d]SFA = Saturated fatty acids (14:0 + 16:0 + 18:0 + 20:0) , MUFA = monounsaturated fatty acids (16:1 + 18:1), PUFA = polyunsaturated fatty acids (18:2 + 18:3 + 20:2 + 20:4)
[e]n-6/n-3 ratio = (18:2 + 20:2 + 20:4) / 18:3
[f]MUFA/PUFA ratio = (16:1 + 18:1) / (18:2 + 18:3 + 20:2 + 20:4)

Tejerina and others (2012) reported significantly higher total phenolic compounds in acorn and grass fed Iberian muscle samples (202.4 µg GAE/g) compared to hogs finished on concentrate diets (178.2 and 162.5 µg GAE/g, respectively). These differences experienced by Tejerina et al. (2012) can likely be attributed to significantly higher concentrations of total phenols in acorns and grasses (13.6 and 5.9 g/GAE^2/kg dry matter, respectively) compared to commercial feed (1.1 g/GAE^2/kg dry matter) used in the study. This suggests that higher phenolic compounds in Iberian diets compared to commercial feed are a product of not only acorns, but equally as important, high concentrations of phenolic compounds and other antioxidants (α-tocopherol, γ-tocopherol) found in grasses Iberian hogs consume when raised extensively on pasture. Since hazelnuts were the primary source of additional phenols in hog diets in this study, this may account for higher total phenols cited in Iberian pork samples compared to samples analyzed in this study.

Concentrations of vitamin E (α-tocopherol) also increased in IM samples as dietary hazelnut inclusion increased. H30 samples had the highest overall vitamin E content (3.00 µg/g), and was significantly greater (P=0.02) than control (1.30 µg/g), but not significantly greater (P>0.05) than H15 (2.37 µg/g) samples. Elevated α-tocopherol concentrations in Iberian muscle samples from extensive acorn and grass feeding regimes (4.7 µg/g) compared to samples from hogs finished on concentrate diets (3.8 and 1.9 µg/g, respectively) was also reported by Tejerina and others (2012). As stated previously, this effect was largely due to the grasses consumed by Iberian hogs fed extensively in *Montanera* regimes, which contained 33.9 mg/kg dry matter of α-tocopherol in tandem with acorns (15.3 mg/kg dry matter), compared to 7.0 mg/kg dry matter in concentrate feed rations (Tejerina et al., 2012). These findings are important due to the instrumental role antioxidant compounds play in scavenging free radicals produced during lipid oxidation (Tucker & Townsend, 2005) and mediating oxidative stability in pork products (Monahan et al., 1992). As reported in Table 1, ground hazelnuts used in H15 and H30 diet treatments in this study contained ~144% greater α-tocopherol content (mg/kg feed) than the commercial

ration (H0). This discrepancy likely accounted for the significant increase in IM α-tocopherol content in H30 samples compared to control (H0).

Lipid oxidation and TBARS

Malondialdehyde (MDA) levels in loin chops (*Longissimus*) from hogs fed finishing rations containing 0, 15 or 30% ground hazelnuts during 10d refrigerated storage are presented in Figure 8. The diet x display time interaction was significant (P=0.036), indicating that not all treatments experienced uniform MDA production during retail display. With respect to MDA production, H0 chops had 21.4-30.7% higher overall MDA values from 2-10 d of refrigerated storage compared to chops from hazelnut-fed hogs. H15 samples experienced the lowest MDA values (0.07-0.18 mg/kg MDA) from 2-10 d of refrigerated retail storage compared to H0 (0.17-0.34 mg/kg MDA) and H30 (0.14-0.26 mg/kg MDA).

The effect slice at day 6 was significant (P=0.013), indicating that MDA production was suppressed by the H15 and H30 diets (0.10 and 0.10 mg/kg MDA, respectively) compared to control (0.33 mg/kg MDA). Day 4 slices approached significance (P=0.078), prefacing the day 6 spread between the hazelnut-fed pork (H15 and H30) and control (H0). However, overall MDA values were low throughout the duration of retail storage in chops from all dietary treatments, with all values below 0.5 mg/kg MDA, which has been reported as the detectable level of rancidity by consumers (Wood et al., 2008).

Table 8. Vitamin E and total phenol content in intramuscular (IM) loin tissue from hogs fed a diet without (H0) ground hazelnuts or with ground hazelnuts added at 15 (H15) or 30% (H30) of the diet.

	H0		H15		H30	
	IM	SEM	IM	SEM	IM	SEM
Vitamin E[d]	1.30[a]	0.38	2.37[ab]	0.38	3.00[b]	0.38
Phenols[e]	178.80	8.64	182.00	8.9	201.96	8.64

[a,b]Means with differing superscripts within a given source (intramuscular tissue) are significantly different ($P<0.05$)
[c]Standard error of the mean
[d]Vitamin E is the α-tocopherol content reported as µg/g sample (ppm)
[e]Phenols are reported as gallic acid equivalents/g (GAE/g)

Table 9. Total phenol content in adipose (AP) tissue from hogs fed a diet without (H0) ground hazelnuts or with ground hazelnuts added at 15 (H15) or 30% (H30) of the diet.

	H0		H15		H30	
	AP	SEM	AP	SEM	IM	SEM
Phenols[e]	89.95	10.01	103.78	10.26	201.96	10.01

[a,b]Means with differing superscripts within a given source (adipose tissue) are significantly different ($P<0.05$)
[c]Standard error of the mean
[d]Phenols are reported as gallic acid equivalents/g (GAE/g)

The findings in this study concerning TBARS suppression in pork products have been observed in previous studies where higher concentrations of MUFA and antioxidants were incorporated in hog diets. Phillips and others (2001) reported significant suppression in TBARS at 2, 4 and 6 d of refrigerated storage in salted and unsalted ground pork patties sourced from hogs supplemented with 170 mg α-tocopherol acetate in a finishing diet compared to controls fed same diet but with 48 mg α-tocopherol acetate supplementation. Iberian studies reported lower TBARS values in pork muscle tissue collected from hogs fed extensively on acorns and grass compared to concentrate-fed hogs, in which the authors also noted greater accretion of α-tocopherol and MUFA in muscle samples of extensively fed hogs compared to hogs fed concentrate diets (Cava et al., 1999; Andrés et al., 2001). These findings corroborate the TBARS results in this study, suggesting that dietary hazelnut inclusion in hog diets can positively impact lipid oxidative stability by depositing higher levels of MUFA and α-tocopherol into pork subcutaneous and intramuscular tissues, compared to concentrate diets. As reported previously, common concentrate diets are high in PUFA (Hoffman & Baker, 2011), which are more susceptible to lipid peroxidation than MUFA (Akoh, 1998). However, given the lack of significant differences in PUFA content in adipose and IM samples (Tables 6 and 7) between diet treatments in this study, the effect of increased α-tocopherol concentrations in hazelnut-fed samples likely had a greater impact on TBARS suppression, given α-tocopherol's ability to scavenge free radical hydroperoxides and delay lipid oxidation (Tucker & Townsend, 2005).

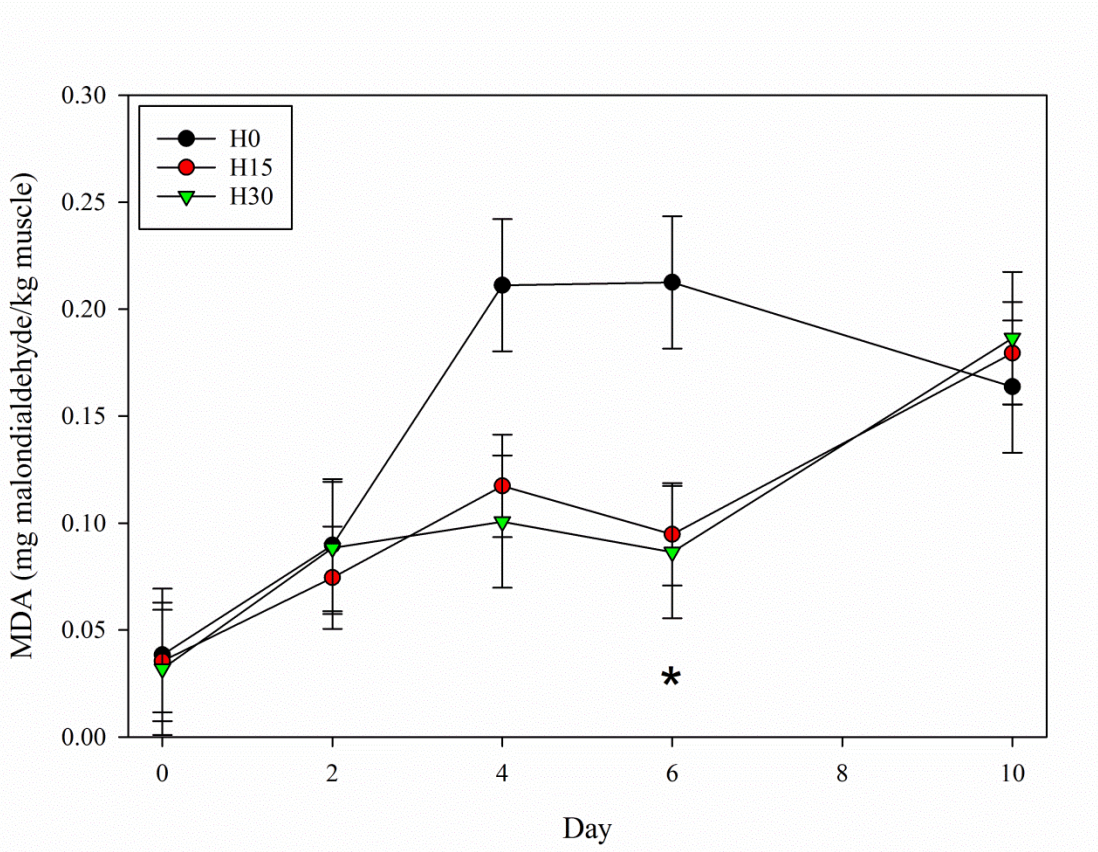

Figure 8. Malondialdehyde (MDA) levels in loin chops (*Longissimus*) from hogs fed finishing rations containing 0, 15 or 30% ground hazelnuts during 10d refrigerated storage.

Instrumental color evaluation

Figure 9 shows objective *a** (redness) values for loin chops (*Longissimus*) from hogs fed 0, 15 or 30% ground hazelnuts in a finishing ration during 10d of refrigerated retail display. No significant difference ($P>0.05$) was detected in *a** values between control (H0) and treatment (H15 and H30) during any day of refrigerated display. Redness values declined in chops from all diet treatments from 0 to 10d lighted retail display (21.76-16.48). There was no significant difference ($P>0.05$) in *L** or *b** color values based on dietary treatment during any day of refrigerated display. Least squared mean *L** values ranged from 62.77-63.28, while *b** values ranged from 20.91-19.02 from 0 to 10d during lighted display in chops from all dietary treatments. Decreases in *a**, *b** and *L** values in pork loin chops throughout lighted retail display were similar to those reported by Phillips and others (2001).

A possible explanation for a lack of color differences between control (H0) and hazelnut (H15 and H30) chops could be due to no significant differences in total PUFA and linoleic (18:2) acid in *Longissimus* intramuscular and subcutaneous back-fat samples ($P>0.05$) when evaluated for fatty acid composition, as previously reported. Since PUFA (18:2n-6, 18:3n-3, 20:2n-6 and 20:4n-6 identified in this study) are more prone to lipid oxidation than SFA and MUFA (Akoh, 1998) and given lipid oxidation's impact on accelerating myoglobin oxidation (Faustman et al., 2010), low concentrations and no significant differences in PUFA in samples from all dietary treatments in this study would likely account for the lack of significant differences in color values experienced in chops from control (H0) and treatment (H15 and H30) hogs during retail lighting display.

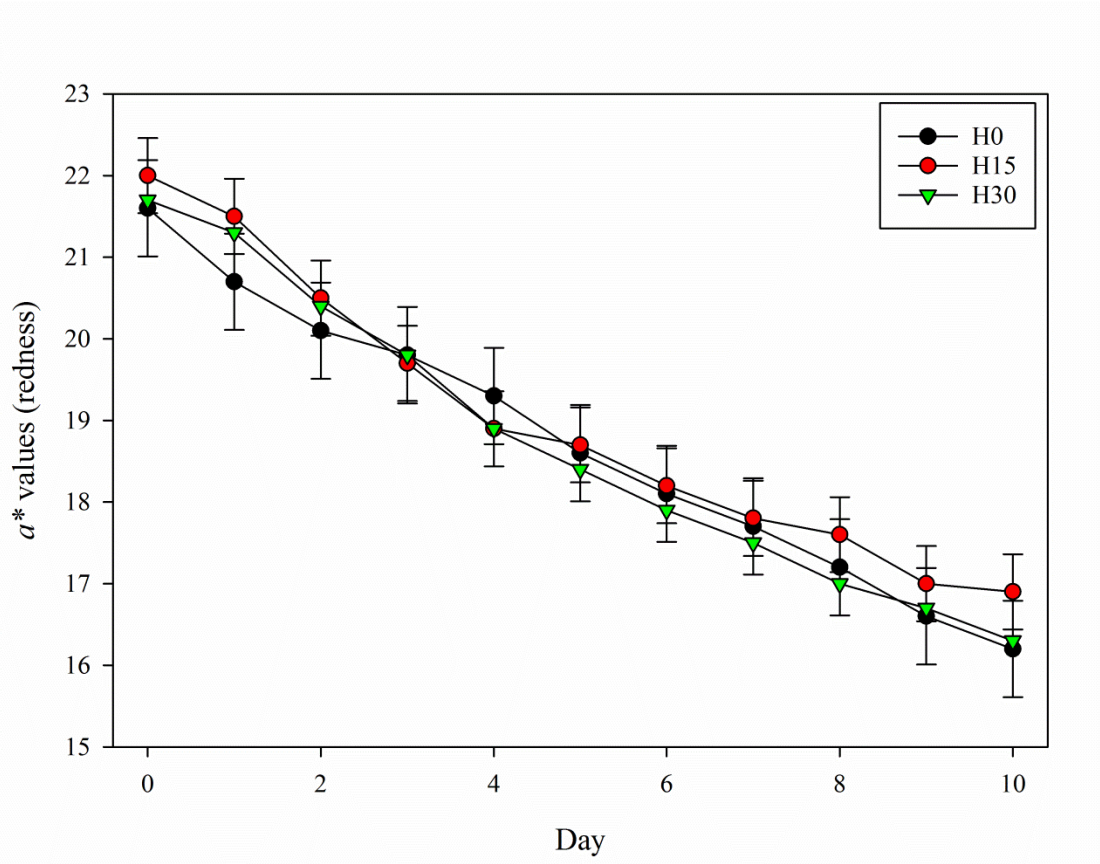

Figure 9. Instrumental *a** (redness) values for loin chops (*Longissimus*) from hogs fed 0, 15 or 30% ground hazelnuts in a finishing ration during 10d of refrigerated retail display.

Purge loss

Least squared mean values for purge loss percentage (%) for loin (*Longissimus*) chops from hogs fed a diet without (H0) ground hazelnuts or fed ground hazelnuts added to diet at 15 (H15) or 30% (H30) ranged 2.40-3.33% from 2 to 6d refrigerated storage in all dietary treatment chops. Purge loss values based on day ranged from 2.78% on day 2 in all chops, to 4.66% on day 6 d of refrigerated storage. No significant difference (P>0.05) in two-way interaction was noted in purge loss % between dietary treatment and day (2, 4 and 6d) of refrigerated storage.

A lack of differences in purge loss between treatments and day of storage may be related to the low TBARS values in samples from all dietary treatments (H0, H15 and H30). Since increases in purge loss % has been shown to be associated with an increase in protein and lipid oxidation interaction in pork *Longissimus* samples (Liu, Xiong & Chen, 2010), and given the low numerical MDA values in muscle samples from all dietary treatments in this study (Figure 8), a significant difference in purge loss % between dietary treatments would not be expected.

5. CONCLUSIONS

Through the inclusion of ground hazelnut supplementation in hog finishing rations, the fatty acid composition of pork improved nutritionally through increases in oleic acid (18:1) and overall MUFA, and decreases in total SFA, namely palmitic acid (16:0). These findings are in agreement with previous studies exploring acorn inclusion in Iberian hog trials which also noted significant increases in MUFA and decreases in SFA in pork fat and muscle depots. Suppression of TBARS can likely be attributed to an increase in α-tocopherol content in muscle due to hazelnut supplementation, yet this increase was not significant enough to produce discernable effects in pork products when evaluated for instrumental color and purge loss.

The implications of these findings may lend validity that hazelnut inclusion in hog diets may impart a fatty acid profile and antioxidant content conducive to the production of dry cured products, namely in the Pacific Northwest region of the United States. Oregon holds a comparative advantage in hazelnut production and its hazelnut yield is expected to double in the next 7-10 years (S. Schussman, personal communication, July 28, 2016). Coupled with price premiums for dry cured/aged meat products, and the potential for a niche market for such meat products in which oxidative stability is crucial to manufacture, the use of hazelnuts as a dietary feed source in pigs may increase profitably for pork producers and meat processors seeking to add value to their product.

Additionally, the ability for hogs fed hazelnuts to readily deposit higher concentrations of MUFA, in turn lowering total SFA content in muscle and adipose tissue may increase marketability of pork products through dietary health claims. As mentioned previously, human diets higher in monounsaturated fatty acids, and lower in saturated fatty acid content, have been shown to lower LDL cholesterol, and may lead to a decreased risk of cardiovascular disease, stroke and certain cancers. Producers and processors wishing to capitalize on these health trends should consider hazelnut incorporation into hog feeding regimes.

Future studies seeking to utilize hazelnuts as a feed source in hog finishing rations must account for isocaloric and isonitrogenous factors when developing feed rations used in trials. These factors likely contributed to control (H0) hogs having a higher finishing weight compared to hazelnut-fed hogs (H15 and H30). Future studies may also want to explore modeling a feeding system more closely related to the Iberian *Montanera* regime, in which hogs are fed extensively in open pasture on acorns and grasses. As noted already, grasses incorporate higher concentrations of phenolic compounds, namely α-tocopherol, as well as α-linolenic (18:3n-3) fatty acids. These compounds may increase total phenolic compounds in pork tissues, which can increase lipid and color oxidative stability in pork products, in tandem with the potential to lower n-6/n-3 ratios.

Future studies must evaluate the impact that hazelnut inclusion may have on meat quality and sensory attributes of pork products. The use of hazelnut derivatives in hog diets, such as hazelnut oil, in place of commonly used constituents like high linoleic soybean compounds, possess the potential to increase oxidative stability and may prolong shelf-life of pork products. Consumer panels evaluating overall acceptability and palatability of hazelnut-supplemented meat products will help determine the hazelnut's overall viability as a dietary livestock feed source.

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