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"Polyphenols for improving food quality and nutraceuticals"

Mini Review

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A Review: Value Added Meat Products With Modified Fatty Acid Profiles

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ABSTRACT

All of us have probably said, at one time or another, "you are what you eat" without fully taking into account the nuanced meaning of those words. Advanced studies in food technology and nutrition science has underscored the importance of making a life time of wise decisions about nutrition and life style to prevent metabolic syndrome and its associated pathologies. To turn a phrase, "you become what you eat", clinically speaking, has never been more relevant or well documented. Dietary fatty acids and their role in Coronary Heart Disease (CHD) is an important topic for research by food scientists and nutritionists. Dietary fats are the most concentrated form of energy (9 kcal/gram), they make foods more flavorful, add lubricity to processed foods, provide satiety; and, aid in the digestion of fat soluble vitamins. Paradoxically, dietary fats have also been linked to increased incidences of CHD; however, the relationship between dietary fats and CHD is complex. Studies indicate mono unsaturated (MUFA) and poly unsaturated fatty acid (PUFA) to saturated fatty acid (SFA) ratios are important dietary factors involved in the propensity for CHD. However, foods with higher levels of MUFAs and PUFAs tend to oxidize faster (resulting in off-aromas, off-flavors and decreased nutritional value in processed foods) and result in product defects. Adapting Good Oxidation Management Practices (GOMP's) including the incorporation of natural polyphenolic oxidation inhibitors has expanded the offerings for meat products meeting desired nutritional profile as well as the shelf life required for "heart healthy" meat products.

KEYWORDS: Natural oxidation inhibitors; Value added meat products; Health lipid indices; Lipid oxidation; Fatty acids; Poly Unsaturated Fatty Acids (PUFA); Mono Unsaturated Fatty Acids (MUFA); Unsaturated Fatty Acids (UFA); Saturated Fatty Acids (SFA); Hexanal; Colorimetry; Gas Chromatography Mass Spectrometry (GCMS); Thiobarbituric acid reactive substances (TBARS); Omega-3 fatty acids; Omega-6 fatty acids; Lycopene; APE, BPE, Butylated hydroxyanisole/Butylated hydroxytoluene (BHA/BHT), Diphosphonic acid (DPA); Omega Fatty Acids (OFA); Atherogenicity index (AI); Thrombogenicity (TI).

INTRODUCTION

The nutritional value of meat products is attributed to their caloric content and high biological value proteins and equally important but much less appreciated a source of essential minerals and B vitamins.[1,2] However nutritionists have generally advised against excessive intakes of meat products due to their sodium levels and fat composition which (perhaps undeservedly) adversely affect cardiovascular health. Recently nutritionists advise[3,4] that calories derived from fat be reduced to 25%-35%, with less than 10% of the calories from saturated fats (SFA), the ω-6 to ω-3 fatty acids be reduced to ratios of 4:1, and the thrombogenicity and atherogenicity indices (AI and IT, respectively) be included in defining "heart healthy diets". Using these guidelines,[5] the nutritional value of meat could be marginalized even further and consequently consumer's perception of meat products as a dietary source for healthful nutrients could become more of a matter of fact than bias. Consequently the estimated demand for meat products current consumption of 60 lbs-100 lbs capita year (USA) could be at risk.

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OBJECTIVE AND MARKET RELEVAVCE

The objective is to review formulations for "heart healthy" value added meat products for the heart healthy conscious consumer. The literature review has shown ample interest in reformulating the nutritional profile in value added meat products and willingness of the consumer to pay more for these products (Sean Fox, Kansas State University agricultural economist). Some meat processors are promoting healthier value-added meat products including a variety of value added meat products such as natural chicken sausages and ground beef with ω-3 fatty acids.

As the ratio of ω-6 to ω-3 fatty acids and AI and IT indices becomes more favorable, the susceptibility to lipid oxidation increases and oxidative stability decreases. Therefore the incorporation of natural oxidation inhibitors is a prerequisite for the commercial success for these types of value added meat products.

Modifying the fatty acid profiles in value added meats can be accomplished ante-mortem through *via* feed rations and or post-mortem[6] by the addition of vegetable oils and fats (e.g., olive, avocado, coconut, canola) into the meat formula.

CHEMISTRY AND CHALLENGES OF LIPID OXIDATION IN VALUE ADDED MEATS

If left unchecked lipid oxidation will have serious organoleptic, myofibril functionality nutritional and economic consequences for value added meat products (Figure 1).

Figure 1: Packages of 80% lean modified atmosphere packaged ground beef stored at 35 °F for 10 days. Ground beef on the left was formulated with a natural oxidation inhibitor (Herbalox® rosemary extract); ground beef on the right was formulated without an oxidation inhibition. Images from color-life studies, Kalsec® Center of Excellence.

Lipid oxidation (also referred to as lipid peroxidation) is pervasive in a wide variety of value added meat poultry and seafood (e.g., fin fish) products. Inhibiting lipid oxidation is even more critical in meat products reformulated to meet more healthful lipid indices. Reviewing how oxidation inhibitors inhibit lipid oxidation helps provide additional in sight and appreciation for their importance in meat formulations. Figure 2 shows the sequence of chemical events associated with lipid oxidation as well as the mode of action of oxidation inhibitors. Generally lipid oxidation proceeds through three stages initiation, propagation and termination. Oxidation inhibitors inhibit oxidation by prolonging the time before the initiation stage. The type of product generated from lipid oxidation varies depending on the stage of oxidation.

Initially peroxides (2) are formed (volatile odorless, tasteless compounds) from the oxidation of free radicals (1), followed by the production of volatile and non-volatile (malodorous and rancid flavors) compounds (3).

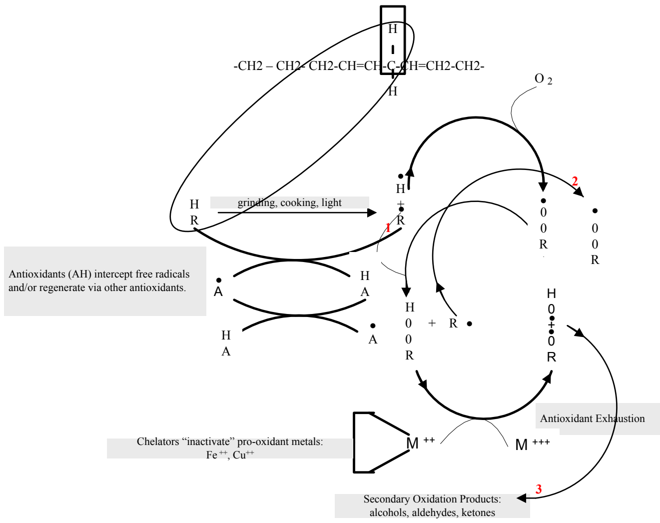

Figure 2: Sequence of chemical reactions involved with lipid autoxidation.[2]

Products from lipid oxidation can be measured using the appropriate analytical method. The effectiveness of oxidation inhibitors are based on inhibiting the formation of these compared to a reference.

As the amount of unsaturated fatty acids increase, the susceptibility to lipid oxidation increases. Unsaturated fatty acids (UFAs=MUFAs+PUFAs) are susceptible to oxidation relative to SFAs for several reasons of which these two are particularly relevant for meat[7] (and food products in general) processing.

- The greater the amount of unsaturated the fatty acids to total fat content in the meat product, the higher the allylic and or bis-allylic equivalent, APE and BAPE, respectively. APE (equation 1) and BAPE (equation 2) are measures of reactivity between unsaturated fatty acids (Figure 3).[8]

Equation 1: $APE=ap_aA_{Ca}+ap_bA_{Cb}+ap_cA_{Cc}+$..........

Where ap_x is the number of allylic positions in a given fatty acid and A_{Cx} is the the amount of the given fatty acid as a percentage.

Equation 2: $BAPE=A_{C18:2}+2A_{C18:3}$………

Where, $A_{C\ UFA}$A is the number of BAPE and CFA is the

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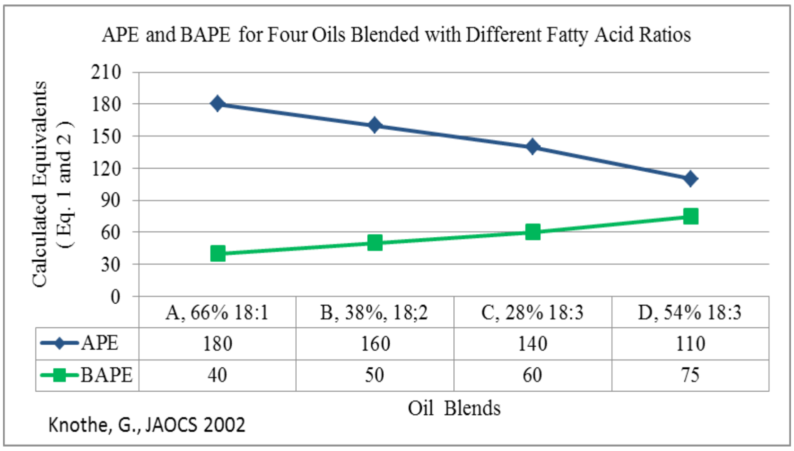

Figure 3: The data in the table shows as the percent PUFAs increases the highly reactive bis-allylic carbons (BAPE) also increases. Modification of data cited in reference 8.

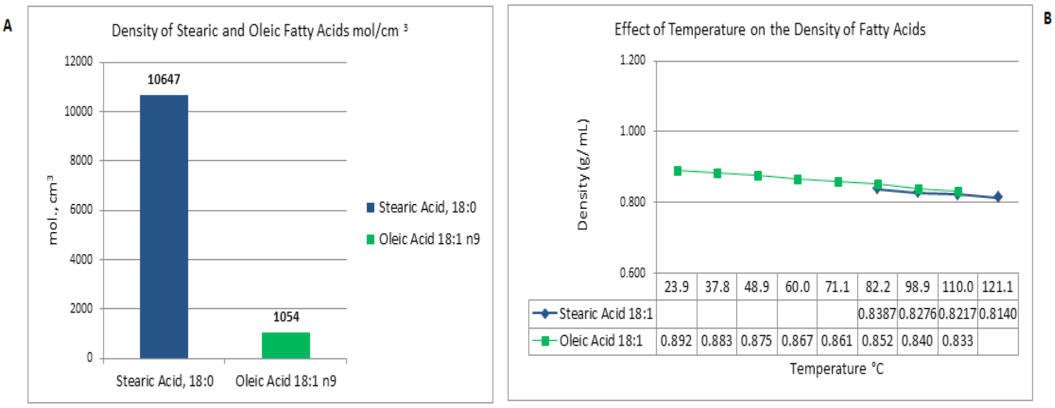

Figure 4A,B: Data in the graph A shows the volume of stearic and oleic fatty acids. Data in graph B shows when the temperature increases, density of fatty acids decrease. Because mass is conserved, the surface area increases. As surface area increases for UFAs, oxidation is more readily initiated and shelf life of meat products reduced. Data modified from[9,10].

amount of the given fatty acid in percent.

- The density of fat changes with its ambient temperature.[9,10] The fat or oil is most dense below the melting point as the ambient temperature reaches and exceeds the melting point the fat or oil becomes less dense, i.e. mass is conserved, volume surface area increases (Figure 4).

Given that all other factors are equal (formulation ingredients, processing methods, myoglobin content, packaging, etc.), shelf life will be determined largely by the degree of unsaturation,[11,12,13] not necessarily the percent total fat in the finished meat product. At this point the challenge for the meat scientist becomes clear. Formulating a value added meat product with higher levels of UFAs in order to make nutritional claims ultimately leads to shelf life challenges. Implementing good oxidation management practices including the early addition of an oxidation inhibitor can change challenges into opportunities.

CHEMISTRY OF OXIDATION INHIBITORS (AUTOXIDATION)

Effective oxidation inhibitors meet the following criteria:

- Efficacy at minimal usage levels.
- Inhibits (not mask) oxidation in a measurable way (as measured by peroxide values, TBARS, GCMS headspace, colorimetry, sensory, etc.).
- Does not impart unexpected or unwanted flavor to the finished product.
- Does not impart an unexpected or unwanted color to the finished product.
- Meet processing requirements, e.g., an oxidation inhibitor that is brine soluble for incorporation into marinades.

The incorporation of natural oxidation inhibitors, e.g. Herbalox® rosemary extract into natural value added meat products warrants a brief review of antioxidant chemistry. In fact, understanding oxidation inhibitors is an essential prerequisite for formulating value added meats to meet the shelf life requirements during distribution and storage in commerce. The data in figure 5 shows the comparative effectiveness for two different types of oxidation inhibitors- Herbalox® rosemary extract and citric acid.

The difference in the effectiveness between the two ox-

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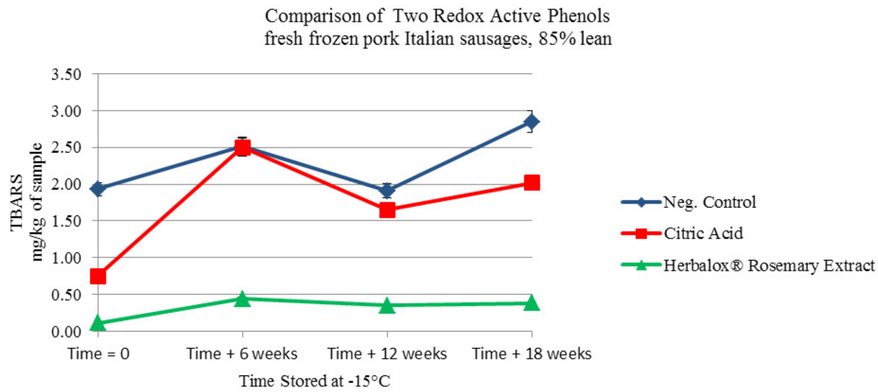

Figure 5: TBARS data shows that citric acid alone is less effective than Herbalox® rosemary extract. These two oxidation inhibitors have different modes of action for inhibiting lipid peroxidation. Data from studies conducted by Kalsec® Center of Excellence.

idation inhibitors as measure by thiobarbituric acid reactive substances (TBARS) is due to principally based on the differences in the mode of action (see Figure 2) of chelators (e.g., citric acid) and free radical interceptors (e.g., carnosol from rosemary extract, figure 6).

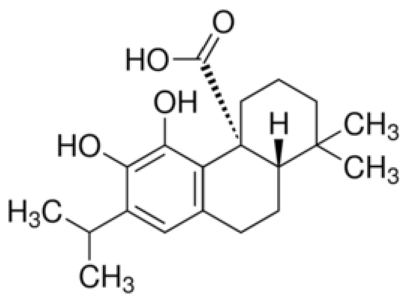

Figure 6: Carnosol from rosemary nusofficinalis, $C_{20}H_{26}O_4$ (a diterpene), molecular weight 330.42.

The antioxidant activity of redox-active polyphenolics delays the onset of autoxidation by inhibiting the formation of free radicals. The relative effectiveness of polyphenolics depends on oxidation-reduction potentials, stability of the phenoxy radical (figure 7), survivability (degree the oxidation inhibitor is lost or destroyed during processing) and distribution in meat tissues.

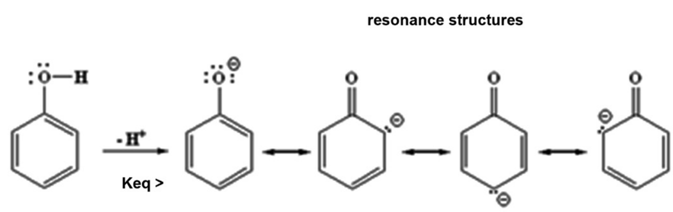

Figure 7: Effectiveness of phenolic molecules as oxidation inhibitors is contributed to the magnitude of the Keq and resonance stability of the oxidized form in food matrices.

Data in figure 8 shows the effectiveness of two redox-active oxidation inhibitors, BHA/BHT (synthetic) and rosemary extract (natural) in delaying the onset of lipid oxidation in frozen lean pork Italian sausages.

INHIBITING OXIDATION IN FATTY ACID MODIFIED VALUE ADDED MEAT PRODUCTS

Forequarter meat from grass fed, grass finished beef contains higher levels of ω-3 fatty acids and consequently higher BAPE values (Figure 9).

The data in figure 9 indicates the health indices most favorably in meat from grass fed beef are:

- ω-6 to ω-3 fatty acid ratios for grass fed and grain fed are 1.4:1 and 7:1, respectively.
- The thrombogenic and atherogenic indices are lower (more desirable) for grass fed beef.
- Fatty acids that do not raise cholesterol (DFA) to fatty acids that raise cholesterol (OFA) is higher in grass fed beef.[14]

Modifying fatty acid profiles, however, presents shelf life challenges. The data in figure 10 shows the effect on increased ω-3 fatty acids on oxidative stability.

The meat scientist may prefer to formulate value added meat products by incorporating UFAs from vegetable oils.[15,16] Meat snack sticks, a fermented sausage product, can be a way of offering convenience, flavor and enhanced nutritional value to consumers. As with grass fed-grass finished beef, as UFAs increase, the requirements for an effective oxidation inhibitor is needed. An added challenge is physically stabilizing the added UFAs. For example, fermented sausages containing 43% chicken thigh meat and 57% pork were formulated to include avocado, olive and palm kernel oils.[17]

PROCESSING, AVOIDING DEFECTS IN HEART HEALTHY, VALUE ADDED MEAT PRODUCT FORMULATIONS

Mixing assures uniform distribution of fat and lean raw ground meats during the processing of sausages. During mixing the myofibril or contractile proteins physically entrap the fat

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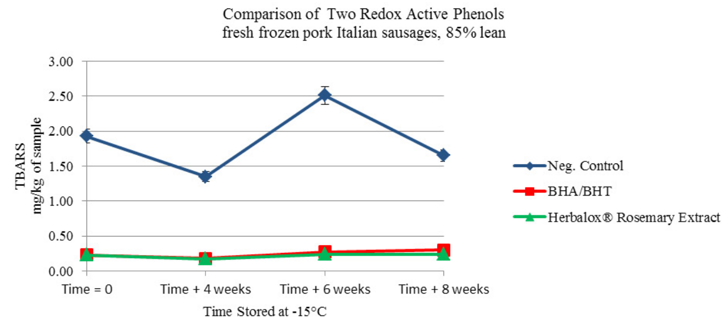

Figure 8: Data shows the comparable performance between a synthetic antioxidant (BHA/BHT) and a natural oxidation inhibitor in frozen fresh Italian sausages.

Fatty Acid analysis (FAME) Calculated Derivative Values for oxidative stability and Nutritional Value							
	Fatty Acid Carbon Notation						
% FA (normalized)	C14:0	C16:0	C18:0	C18:1	C18:2	C18:3	Total
Grass Fed	6.3%	39.5%	23.4%	27.5%	2.00%	1.4%	100%
Grain Fed	11.1%	43.2%	9.60%	33.9%	2.00%	0.30%	100%
FA Distribution (millimoles)							
Grass Fed	0.27	1.54	0.82	0.98	0.07	0.05	3.73
Grain Fed	0.49	1.68	0.34	1.20	0.07	0.05	3.83
FA Distribution (mole fraction)							
Grass Fed	7.3%	41.3%	22.0%	26.1%	1.90%	1.40%	100%
Grain Fed	12.9%	44.4%	8.90%	31.7%	1.90%	0.20%	100%
Stability and Nutritional Value	Calc. IV	%IV (from C 18:3)	APE	BAPE	IT	AI	DFA/ OFA
Grass fed	31.0	0.12%	62	5	0.47	1.06	1.53
Grain Fed	33.0	0.02%	72	2	1.84	2.38	0.62

Figure 9: Fatty acid profiles (GC, FAME analysis by Kalsec® Center of Excellence) shows grass fed-grass finished beef has higher levels of ω-3 fatty acids

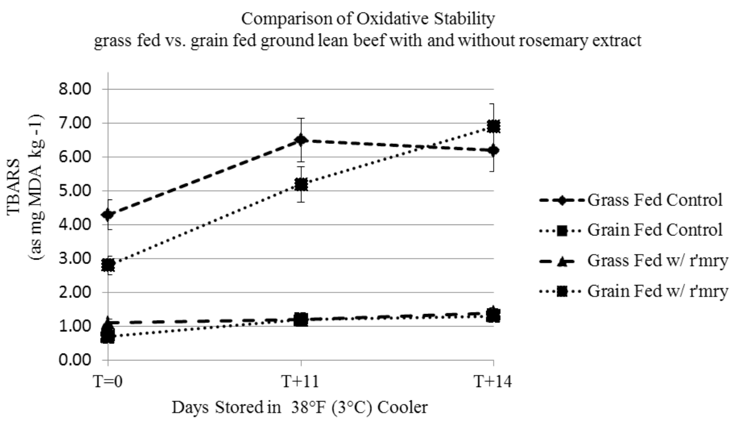

Figure 10: Grass fed-grass finished beef is less stable than grain fed beef. The addition of a natural oxidation inhibitor (Herbalox® rosemary extract at 0.05% based on antioxidant activity in the meat) improves stability in ground beef. Note, in the legend rosemary is the abbreviation for rosemary extract. Data from studies conducted at Kalsec® Center of Excellence.

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(and added oils) to prevent the fat from rendering our during drying and/or cooking. The amount of fat that renders out of the sausage is referred to as "cook-out" (Figure 12).

The diagrammatic representation in figure 13 shows the relationship between mixing, cook-out and raw meat temperature.

The tendency for fat (and oils) to render out is related to data given and can be expressed in a modified version of Stokes Law.

Equation 3: Stokes Law=V=$D^2(d_2 - d_1)$÷viscosity

Modified Stokes Law for sausage application=$D^2(d_l - d_f)$÷Viscosity

Where, D^2=size (diameter) of fat particles or oil droplets.
d_l=density of lean phase in the sausage batter.
d_f=density of fat phase in the sausage batter.

Stokes Law states that incidences of "fatting out" for a given meat formulation increases exponentially with the diameter of the fat particles and linearly with the density of the fat phase in the sausage formulation (also reference Figure 3).

Reformulating the composition and amount of the added vegetable oil and processing technique to increase the extraction of myofibril protein eliminated "fatting out" (figure 14), as can be seen in figure 15

The meat snacks (figures 11 and 15) have a 80% lean content, 0.90 Aw, 4.6 pH and a moisture protein ratio (MPR) estimated at 2.3:1.

The targeted shelf life for a fermented meat product ranges from 90 days to180 days under refrigerated conditions. Oxidative stability is measured by cure color stability (reflectance CIE L*a*b* colorimetry) as well lipid oxidation products (GCMS headspace or TBARS).

FORMULATION: Fermented Meat Snack Sticks

Ingredients	**%**
Chicken+Pork (92% lean)	92.32%
Salt	1.62%
Sweetener	1.15%
Kalsec® Seasoning	0.37%
Natural cure (1.6% NO_2)	0.38%
Chilled Water	2.77%
Acidi Lacti culture	0.08%
Natural ascorbic acid	0.04%
Lycopene inclusions	1.27%
Total	**100.00%**

Figure 11: Formulation for fermented meat snack stick, 10% of the fat from meat was replaced with a blend of avocado, olive and palm kernel oils. The seasoning contains Kalsec®'s Duralox® 63.55.50.a blend of flavoring, spice extracts and rosemary extract (oxidation inhibitor). Formulation by Kalsec® Center of Excellence.

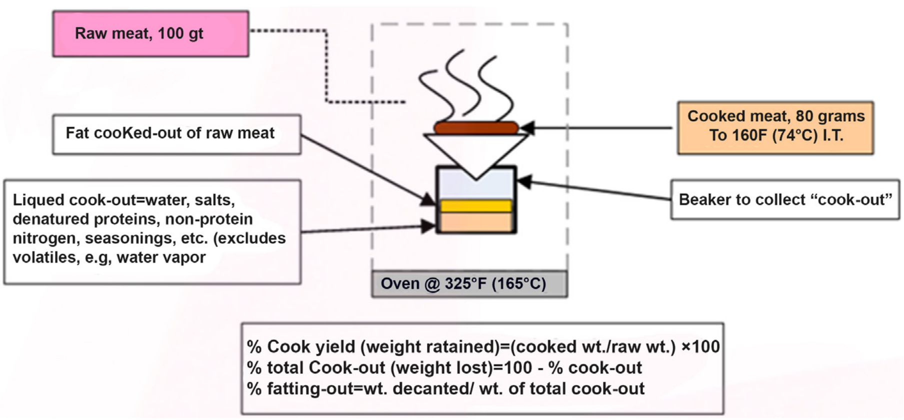

Figure 12: The optimum mix time for sausages can be determined by comparing the cook-out at different mix times. Drawing (Microsoft® Office Visio, 2003) and definitions from Kalsec® Center of Excellence.

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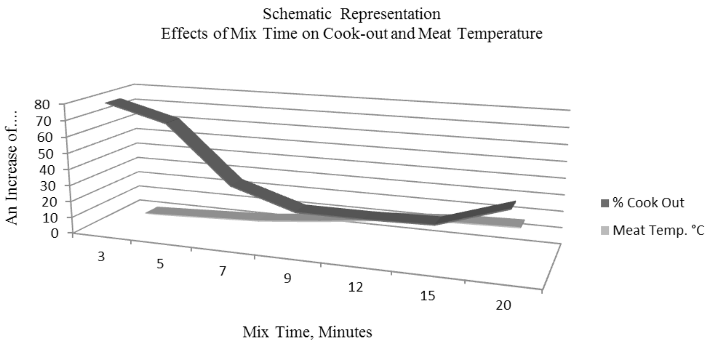

Figure 13: The principle demonstrated shows, for a given meat formulation, increasing mix time results in a temperature rise in the meat batter and an increased tendency for fat to render out during drying and/or cooking. Generalized Model developed by Kalsec® Center of Excellence.

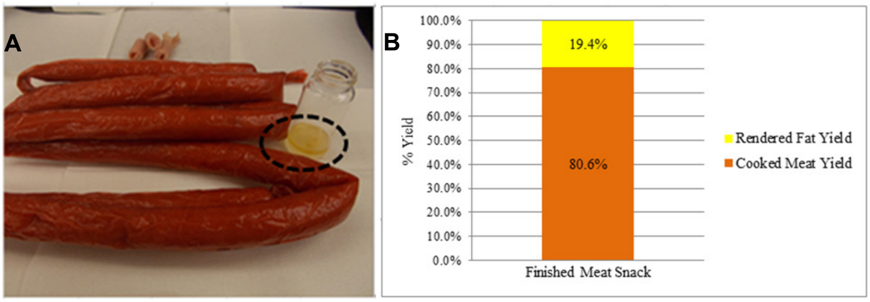

Figure 14A,B: The photograph shows fat and oil rendered or "fatting out" (black dotted circle) due to over mixing the raw meat batter prior to stuffing and thermal processing. Data in the graph shows increasing the addition of vegetable derived oils can cause meat defect in the finished product referred to as "fating or oiling out". Data collected from studies conducted by Kalsec® Center of Excellence.

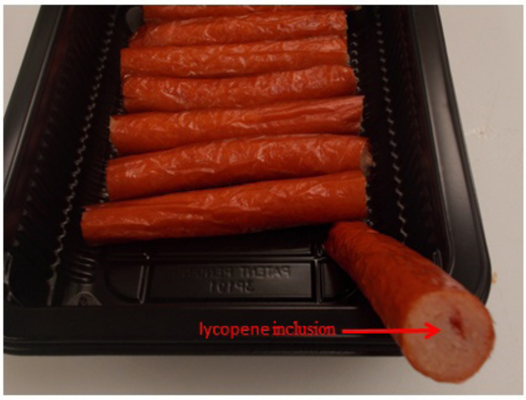

Figure 15: Meat snack sticks with modified fatty acid profile containing lycopene inclusions (made from Kalsec® #59.01 lycopene in porcine 180 bloom strength gelatin). The meat snacks in the photos have a 80% lean content, 0.90 Aw, 4.6 pH and a moisture protein ratio (MPR) estimated at 2.3:1. Meat snack sticks formulated and processed in the Kalsec® Center of Excellence, reference Figure 10.

ASSESSING AND COMPARING "PRODUCT FIT" FOR THE HEART HEALTHY MARKET FOR VALUE ADDED MEAT SNACK STICKS

Nutritional indices for the reformulated meat snack stick can compared to conventionally formulated meat snack sticks (figure 16) to assess their contribution and value to the processor's product portfolio.

Given the nutrient composition and densities in the reformulated meat snack, a multivariate analysis can be conducted to determine the relative position of the reformulated meat snack to other snack products in the market (Figure 17).

The analysis in figure 17 shows the meat scientist the position of the "healthy" meat snack has relative to other snacks in the market. The analysis shows "healthy" meat snack sticks are nutritionally different than many types of snacks because they have lower calories from carbohydrates and relatively less sodium.

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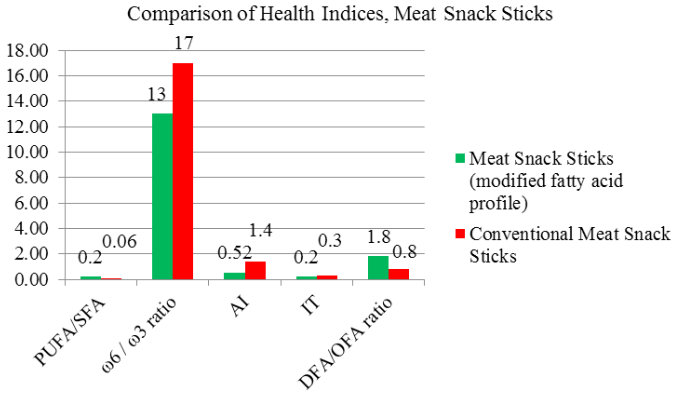

Figure 16: Data shows meat snack sticks with modified fatty acids (with 70% avocado, 15% olive and 15% palm kernel oils in the blend) have more favorable health indices. Indices calculated from studies conducted by Kalsec® Center of Excellence.

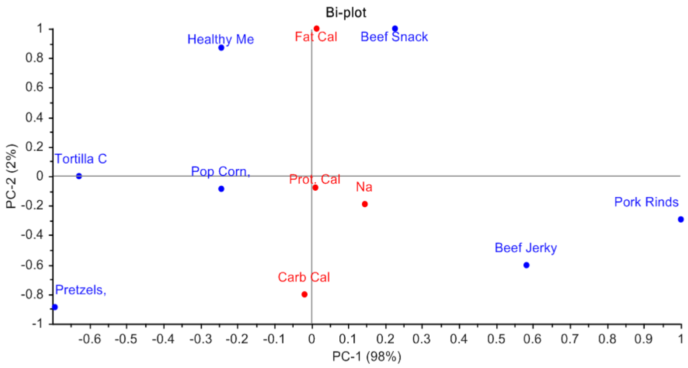

Figure 17: The Multivariate analysis (MVA) of data based on the chemical composition of various snack foods obtained from USDA nutrient data base then analyzed using CAMO® UNSCRAMBLER™ statistical software. The descriptor “Healthy Me” in the data is an abbreviation for “Healthy Meat Snacks”.

DISCUSSION

In a consumer driven market, the company that is first to market with a product that is visually appealing and flavorful has a decided advantage. Consumers seeking options healthier foods are no exception, i.e. good nutrition should not be compromised by oxidized flavors. Modifying fatty acid profile of meat products to provide consumers options that improves and promotes cardiovascular health has been the focus of much research. Generally, foods with PUFA/SFA of 0.4 to 1.0; ω-6:ω-3 ratios below 7; lower atherogenic index (AI) and thrombogenic index (TI) are considered to be more “heart healthy”. In addition, fatty acid profiles with favorable atherogenic and thrombogenic indices contain high DFA/OFA ratios that also fit into the indices that are favorable for “healthy eating”. To accomplish these nutritional requirements the meat scientist will formulate products with higher MUFAs and PUFAs; however, as shown, even incremental additions of UFAs increases the susceptibility to oxidation and incidences of defects (oiling out) in meat products with modified fatty acid profiles.

Following good meat processing techniques including the incorporation of natural oxidation inhibitors offers attractive, flavorful choices that fit the life style of consumers pursuing a healthful diet.

CONCLUSION

With great opportunities there are also great challenges. In the case of value added meat products with modified fatty acid profiles, meeting those challenges includes preventing product defects e.g. oiling out, and incorporating natural oxidation inhibitors.

Studies cited in this paper show the effectiveness of natural oxidation inhibitors in meeting shelf life requirements of meat products designed for the health conscious consumer.

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