



An investigation of the formulation and nutritional composition of modern meat analogue products

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ABSTRACT

Meat analogues, or plant-based products that simulate the properties of traditional meat products, have secured a position in the conversation of protein foods. Rapid growth of the meat analogue industry is occurring in the global food marketplace in both the retail and food service sectors. The purpose of this review was to investigate the ingredients used in the formulation of modern meat analogues, evaluate the nutrient specifications of modern meat analogue products, and then form a comparison with traditional meat products. Based on this investigation, it was determined – firstly, the ingredients used in the formulation of modern meat analogue products make these products fit under the classification of ultra-processed foods; and secondly, the nutrient specifications of popular meat analogue products can effectively simulate the nutrient specifications of the meat products they are attempting to simulate. Therefore, based on these findings, modern meat analogue products can offer roughly the same composition of nutrients as traditional meat products, albeit with many different ingredients and a high level of further processing.

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1. Introduction

The current food landscape in North America can be described as one where consumers request and will pay premiums for foods that are minimally processed, nutritious, and healthy [1,2]. One of the few exceptions where market trends suggest consumers are willing to purchase and consume ultra-processed foods is the case of meat analogues, or meat simulation products. Meat analogues are defined as food products that simulate the aesthetic, organoleptic, and chemical characteristics of traditional meat products [3–5]. While not all meat analogues are categorized as ultra-processed foods, many modern meat analogue products in the current food marketplace would fit this definition. Ultra-processed foods are defined as foods manufactured with little or no whole foods, and with processed ingredients or substances that are extracted/refined from whole foods (i.e. protein isolates, oils, hydrogenated oils and

fats, flours and starches, variants of sugars and refined carbohydrates, and/or other value-added ingredients) [6–11]. Several consumer reviews have praised modern meat analogues for their ability to meet consumer expectations by providing meat-like appearance, texture, flavor, and mouthfeel, while easing the hesitation some consumers have with traditional meat production such as environmental concerns and animal welfare issues [3,4,12,13]. There is currently a justifiable debate with the food industry on the nutritional health and wellness of modern meat analogues. On one hand, increased consumption of plant-based foods is generally considered healthy [14–16] and modern meat analogue products do often times meet macro-nutrient composition of traditional meat products [4]. However, increased consumption of ultra-processed foods and reduced consumption of whole food structures may elicit unintended, and frankly unknown, nutritional consequences [7,8,17]. Therefore, the primary purpose of this review was to investigate available scientific literature and provide discussion surrounding the topic of modern meat analogues and the nutritional health and wellness of these products. Successively, a detailed history, a description of ingredients and processing techniques, and a nutritional comparison with traditional meat products was included in this review.

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2. History of meat analogues

Plant-based meat analogues are not a new food category and do not necessarily represent an entirely new concept. There are several previous reviews that have discussed the illustrious history of meat analogues and other plant-based meat replacements that simulate the attributes of meat [4,13,18–20]. Most notably, Shurtleff & Aoyagi (2014) provided a timeline with hundreds of chronological events occurring throughout the world detailing the history of meat alternatives spanning from the year 965 CE to the year 2014 [19]. This document reported the earliest known reference to a soy-based tofu product was 965 CE in China [19]. There would be several other developments and references of plant-based meat analogues throughout history, but it was not until the mid-to late- 1900s that food technology really began to develop in this area [19]. In fact, many of the modern technologies that are used to manufacture meat analogues today, including biopolymer spinning and extrusion were first patented in 1947 and 1954, respectively [19]. Historically, the primary protein ingredients used in meat analogues have varied, with historical reference of tofu (a soy product) dating back to 965 CE, wheat protein dating back to 1301, yuba (a soy product) dating back to 1587, tempeh (a soy product) dating back to 1815, and combinations of nuts, cereals, and legumes dating back to 1895 [19]. Presently, the major sources of plant-based proteins used in meat analogues remain soy and the wheat protein gluten, while other protein sources such as legumes/pulses (pea, lentil, lupine, chickpea, and others), and fungi (mycoprotein, yeasts, and mushrooms) are also used [4,13].

In recent times (2015–2020), a global expansion of the meat analogue marketplace is occurring with rapid growth in product offering and availability. As indicated by Kyriakopoulou et al. (2019), the marketplace for meat analogue products in Europe and North America has expanded beyond just vegetarian consumers to now include meat eating and meat loving consumers [13]. According to Mordor Intelligence (2019), the market snapshot of the meat analogue marketplace is expected to grow at a 7.9% compound annual growth rate between the years of 2019 and 2024, with the fastest growing market being the Asia Pacific and the largest market being Europe [21]. Overall, the global plant-based meat industry is predicted to reach USD\$21.23 billion by 2025 [22]. While this pales in comparison with the 2025 global prediction of the meat, poultry, and seafood industry, which is predicted to reach US\$7.3 trillion by 2025 [23], the plant-based meat industry will continue to grow as a niche market and reach the plates and palates of many more consumers in the future.

3. Ingredients of meat analogues

Before processing techniques used to manufacture meat analogue products is fully described and discussed, the ingredients used in the formulations of meat analogues must be fully understood. For evaluation purposes, the ingredients in several popular modern meat analogue products and traditional meat products were outlined in Table 1. The information provided in Table 1 was sourced from the publically available information found on product labels of the selected products. The products chosen for this review were certainly not an exhaustive list of the products in the marketplace, but represented popular products at the time this review was written. Similarly, the traditional meat products used in this review was not an exhaustive list, but represented popular products that the meat analogues evaluated in this review simulate. Information for ingredients used in the formulations of meat analogue and traditional meat products were current as of September 2019 in accordance with the information on manufacturer labels, which are also available to the general public.

3.1. Protein ingredients

The protein ingredients used for the manufacture of meat analogues is undoubtedly one of the most important components for product identity and product differentiation. Proteins have important structure-function relationships in terms of hydration and solubility, interfacial properties (emulsification and foaming), flavor binding, viscosity, gelation, texturization, and dough formation [24,25]. Furthermore, processing-induced physical, chemical, and nutritional changes occur in proteins and are dependent on the protein source [24–27]. From a nutritional standpoint, the impact of further processing on the nutritional quality of proteins is certainly an immature area of research. In a review paper presented by Meade et al. (2005), processing conditions, such as heat treatment, high pressure, pH change, protein fractionation, enzymatic reaction, milling, pressure, and fermentation were all outlined as conditions eliciting significant nutritional effects on proteins, and more specifically the nutritional availability of amino acids [24]. For the purpose of this review, the aim was to investigate ingredients and macro-nutrient composition; however, future research efforts are necessary to account for nutritional effects on proteins caused by processing and preparation.

There are several plant-based sources of proteins currently used in the manufacture of meat analogues. The focus of the remaining portion of this section is to provide background information on each of these sources of proteins and investigate the nutritional implications of single-use or the combination-use of these ingredients.

Animal derived products contain a complete source of protein, which is defined as an adequate proportion of each of the nine indispensable amino acids necessary in the human diet and acceptable digestibility of these amino acids. Previous research efforts have established that while some plant-based food sources contain a completed source of protein, many are lacking or limiting in one or more indispensable amino acids [28,29]. Furthermore, the digestibility of plant protein is often compromised by a number of different factors, which is not generally the case for animal derived protein [30].

Soy protein is historically the most common protein used in meat analogue products. Several research studies have been used to form comprehensive reviews on the positive, health-improving effects of soy protein consumption with improvement in lipid metabolism [31,32] and cardiovascular health [33]. Nutritionally speaking, processed soy protein (i.e. isolated soy protein and soy protein concentrates) have been shown to have greater availability of indispensable amino acids compared with unprocessed, or minimally processed soy protein [34,35]. This has enabled processed soy protein to obtain protein digestibility-corrected amino acid scores (PDCAAS) of 1.00, which is the greatest obtainable PDCAAS score and is comparable to animal derived foods like meat, eggs, and dairy products [29,35]. Even so, soy protein generally contains lower values for many amino acids compared with animal derived products, especially for the indispensable amino acids methionine and lysine [29,36]. Functionally speaking, soy protein isolates and concentrates are more advantageous compared with unprocessed or minimally processed soy protein because of improvements on color (minimally processed soy protein generally darkens meat products) and flavor (minimally processed soy protein generally elicits a bitter flavor) [3,37]. Another consideration manufacturers should consider when selecting a soy protein to use in a meat analogue formulation is advantages that textured soy protein can offer. Malav et al. (2015) speculates that a majority of manufacturers would use a combination of textured and non-textured soy protein when formulating meat analogues [38]. Nonetheless, most current literature encourages the presence of additional protein sources beyond that of just soy ingredients when formulating meat analogues – both for nutrition and functional purposes [3,13,38].

Table 1
Ingredient list of several meat analogue and traditional meat products – current as of September 2019.

| Product | Traditional Meat Product Simulated | Ingredient List | Company | Country | Reference |
|--|------------------------------------|--|--|---------|---|
| Meat analogue products Beyond burger | Beef burger | water, pea protein isolate, expeller-pressed canola oil, refined coconut oil, rice protein, natural flavors, cocoa butter, mung bean protein, methylcellulose, potato starch, sunflower oil, apple extract, salt, potassium chloride, vinegar, lemon juice concentrate, sunflower lecithin, pomegranate fruit powder, beet juice extract (for color) | Beyond Foods | USA | https://www.beyondmeat.com/products/the-beyond-burger/ |
| Impossible burger | Beef burger | water, soy protein concentrate, coconut oil, sunflower oil, natural flavors, 2% or less of: potato protein, methylcellulose, yeast extract, cultured dextrose, food starch modified, soy leghemoglobin, salt, soy protein isolate, mixed tocopherols (vitamin e), zinc gluconate, thiamine hydrochloride (vitamin b1), sodium ascorbate (vitamin c), niacin, pyridoxine hydrochloride (vitamin b6), riboflavin (vitamin b2), vitamin b12. | Impossible Foods | USA | https://faq.impossiblefoods.com/hc/en-us/articles/360018937494-What-are-the-ingredients- |
| MorningStar farms grillers original burger | Beef burger | water, wheat gluten, soy flour, vegetable oil (corn, canola and/or sunflower oil), egg whites, calcium caseinate, corn starch, contains 2% or less of: onion powder, soy sauce powder (soybeans, salt, wheat), methylcellulose, cooked onion and carrot juice concentrate, salt, natural flavor, soy protein isolate, garlic powder, spices, sugar, gum acacia, whey, yeast extract, xanthan gum, potato starch, tomato paste (tomatos), onion juice concentrate. | MorningStar Farms, Kellogg's | USA | http://smartlabel.kelloggs.com/Product/Index/00028989100801 |
| Boca all American veggie burger | Beef burger | water, soy protein concentrate, reduced fat cheddar cheese (pasteurized part-skim milk, cheese culture, salt, enzymes, annatto (color), vitamin a palmitate), corn oil, wheat gluten, contains less than 2% of: caramel color, methylcellulose, soy protein, dried onion, cheese powder (cheddar cheese (milk, cheese culture, salt, enzymes), cream, salt, sodium phosphate, lactic acid), salt, natural flavor (non-meat), hydrolyzed soy protein, disodium inosinate and disodium guanylate, sesame oil, spices and herbs, dried garlic, mannitol, yeast extract. | Boca Food Company, Kraft Foods | USA | https://www.bocaburger.com/products/00759283673219 |
| Gardein meatless meat balls | Beef meat balls | water, textured vegetable protein (soy protein concentrate, barley malt extract), canola oil, vital wheat gluten, soy protein isolate, enriched flour (wheat flour, niacin, reduced iron, thiamine mononitrate, riboflavin, folic acid), methylcellulose, dried onion, spices, yeast extract, sea salt, malted barley, dried garlic, organic cane sugar, organic distilled vinegar, natural flavors, salt, cane sugar, yeast, pea protein. | Garden Protein International, Pinnacle Foods | Canada | https://www.gardein.com/products/meatless-meatballs/ |
| Tofurky ham roast with glaze | Boneless pork ham | water, vital wheat gluten, organic tofu (water, organic soybeans, magnesium chloride, calcium chloride), expeller pressed canola oil, contains less than 2% of sea salt, spices, granulated garlic, cane sugar, natural flavors, natural smoke flavor, color (lycopene, purple carrot juice), oat fiber, carrageenan, dextrose, konjac, potassium chloride, xanthan gum. | Tofurky, Turtle Island Foods | USA | https://tofurky.com/what-we-make/roasts/ham-roast/ |

Table 1 (Continued)

| Product | Traditional Meat Product Simulated | Ingredient List | Company | Country | Reference |
|---|------------------------------------|--|-------------------|----------------|---|
| Quorn brand chik'n nuggets | Breaded chicken nuggets | mycoprotein (43%), wheat flour, canola oil, egg white, yeast extract. contains 2% or less of wheat starch, potato dextrin, salt, wheat gluten, dextrose, whole egg, pea fiber, b proteins, calcium chloride, calcium acetate, turbinado sugar, black pepper, yeast, onion powder, sage, sugar. | Quorn Foods, Inc. | United Kingdom | https://www.quorn.us/products/quorn-meatless-chicken-nuggets |
| Traditional meat products | | | | | |
| Ground beef (93% lean, 7% fat) | | Beef | | | USDA Food Composition Database https://ndb.nal.usda.gov/ndb/search/NBDID:23472 NBD ID: 23,474 |
| McDonald's beef patty | | 100% pure beef, grill seasoning includes: salt, spice (pepper), sunflower oil (used as processing aid) | McDonald's Corp. | USA | https://www.mcdonalds.com |
| Tyson fully cooked homestyle beef meatballs | | ground beef (not more than 30% fat), water, textured vegetable protein (soy protein concentrate, caramel color), onions, tomato puree (tomatoes, citric acid), breadcrumbs (wheat flour, dextrose, salt, yeast, soybean oil), seasoning (salt, dehydrated onion, dehydrated celery, garlic powder, spices, soybean oil), minced onion, red bell peppers, soy protein concentrate, potassium and sodium phosphates, natural flavor. | Tyson Foods, Inc. | USA | https://www.tysonfoodservice.com/products/meatballs/premium-fully-cooked-meatballs/30023700038785 |
| Tyson fully cooked chicken nuggets | | chicken, water, salt, and natural flavor. breaded with: wheat flour, water, wheat starch, white whole wheat flour, salt, contains 2% or less of the following: yellow corn flour, corn starch, dried onion, dried garlic, dried yeast, brown sugar, extractives of paprika, and spices. breading set in vegetable oil. | Tyson Foods, Inc. | USA | https://www.tyson.com/products/breaded-chicken-nuggets |
| Hormel cure 81 classic boneless ham | | ham cured with water, salt, potassium lactate, dextrose, modified potato starch, sodium phosphates, sodium erythorbate, sodium nitrate. glaze ingredients: sugar, brown sugar, spice, honey, maltodextrin, silicon dioxide (anti caking agent), yellow 5lake, red 40 lake, blue 1 lake. | Hormel Foods, LLC | USA | http://hormel.com/Brands/Cure81/Hormel-Cure81-Boneless-Hames/hormel-cure-81-Classic-Boneless-Ham |

Cereal proteins are classified in several different categories based on the plant of origin (e.g. wheat, rice, barley, oats), and the degree of processing (e.g. seeds, flour, isolates, flakes) [38]. Wheat is the most historically used type of cereal protein used in meat analogue products, with seitan dating back several centuries – however, rice, barley, and oat ingredients are common among the ingredient labels of modern meat analogue products. Nutritionally speaking, cereal ingredients are generally higher in carbohydrate content and much lower in protein content compared with soy. However, when focusing solely on protein of cereal ingredients, protein digestibility scores are typically lower compared with other sources of protein, because of suboptimal amino acid profile and low protein digestibility [39]. Cereal proteins have lower values for many amino acids compared with other protein sources, but the first limiting amino acid in cereal proteins is generally lysine [3,39,40]. Digestibility of cereal proteins can be affected by internal factors (i.e. structural feature, protein folding/crosslinking, amino acid sequence) and external factors (i.e. anti-nutritional factors like protease inhibitors, tannins, phytates) [39]. Functionally speaking, cereal proteins are very useful to manufacturers of meat analogues from a structural standpoint. The structural network in most cereal

proteins can be described as visco-elastic, which can help form a successful bind and provide the necessary consistency in meat analogues, while attributing the fibrous-like texture found in ground meat products [4,13,38].

Legume proteins (i.e. pea, lentil, lupine, chickpea, mung bean, and others) are gaining in popularity among manufacturers of meat analogues in recent years. Kyriakopoulou et al. (2019) discussed the promising application of pea protein when structured with high-moisture extrusion [13]. Nutritionally speaking, legume proteins are generally low in methionine and are greatly affected by challenges with digestibility (mainly anti-nutritional factors) [41]. While it is generally assumed that processing improves availability and digestibility of proteins, the protein digestibility-corrected amino acid scores (PDCAAS) of unprocessed legume products are generally in the 0.40 to 0.70 range, which is not comparable to animal derived proteins or processed soy protein [29]. From a functional standpoint, legume proteins offer great complementary function to other protein ingredients with many promising and unique processing attributes [13].

Mycoprotein is a fungus product first described in the 1960s as an eco-friendly protein alternative [42]. Various fermentation and

processing techniques are involved with the creation of mycoprotein, and many studies have investigated the use of mycoprotein in various food applications [43]. Nutritionally speaking, mycoprotein is comparable to animal-derived sources of protein with a protein digestibility-corrected amino acid scores (PDCAAS) of 1.00 [3,29,44]. From a functional standpoint, mycoprotein is generally combined with other ingredients, most commonly egg albumin, to improve processing characteristics [38].

3.2. Lipid ingredients

Meat analogues are traditionally low in lipid content [4,13]; however, modern meat analogue products contain considerably greater lipid content compared with traditional meat analogue products. In fact, the lipid content of modern meat analogue products is roughly equivalent to traditional meat products. Similar to the strategy used with protein ingredients, generally a variety of lipid ingredients (fats/oils) are used in the formulation of meat analogues. Lipid ingredients used in modern meat analogues include canola (rapeseed) oil, coconut oil, sunflower oil, corn oil, sesame oil, cocoa butter, and many other sources of vegetable and plant oils. As a previous review conducted by Kyriakopoulou et al. (2019) discussed, the role of fats and oils in meat analogue formulations is to contribute to the juiciness, tenderness, mouthfeel, and flavor release of the product, yet significant consideration should be centered on the effect of the fats and oils during processing and preparation to prevent excessive lubrication and stickiness [13]. From a nutrition standpoint, the healthiness of dietary fats and oils in the human diet are highly debated. Generally, nutritionists, dieticians, and government organizations (like the American Heart Association) have recommended dietary patterns that limit consumption of saturated fats and trans fats; and promote consumption of unsaturated fats [45–47]. The link between saturated fats and trans fats with increased bad (low density lipoprotein) cholesterol levels and reduced good (high density lipoprotein) cholesterol levels is the rationale that has led to these recommendations. Yet, recent literature suggests that the link between consumption of saturated fats from animal derived sources and increased bad cholesterol levels may not be as strong as it once was perceived to be [48–50]. The debate on whether saturated and trans fats are healthy or unhealthy is beyond the scope of this review. Therefore, this review will focus on the composition of the aforementioned fats/oils used in modern meat analogue products and how they compare to traditional meat products.

The fatty acid composition of ground beef (93% lean meat, 7% fat; cooked, pan-broiled; NBD ID: 23474) is comprised of 3.29 g saturated fat/100 g of product, 3.27 g monounsaturated fat/100 g of product, 0.39 g polyunsaturated fat/100 g of product, and 0.27 g trans fat/100 g of product [51]. The fatty acid composition of chicken (Tyson fully cooked chicken nuggets; NBD ID: 45253728) is comprised of 4.44 g saturated fat/100 g of product, 6.67 g monounsaturated fat/100 g of product, 6.67 g polyunsaturated fat/100 g of product, and 0.00 g trans fat/100 g of product [51]. The fatty acid composition of pork ham (Hormel cure 81 classic boneless ham; NBD ID: 10851) is comprised of 1.19 g saturated fat/100 g of product, 1.75 g monounsaturated fat/100 g of product, 0.37 g polyunsaturated fat/100 g of product, and 0.00 g trans fat/100 g of product [51]. The major fatty acids that make up the fatty acid composition of these complete meat products are long chain fatty acids such as palmitic acid (C_{16:0}), stearic acid (C_{18:0}), oleic acid (C_{18:1}), and linoleic acid (C_{18:2}).

The fatty acid composition of plant-based fats/oils differ substantially compared to animal-derived fats – with short chain, intermediate chain, and long chain fatty acids represented in varying proportions. Several research studies have investigated the fatty

acid composition of different plant-based fats and oils to further confirm these evaluations [52–54].

The fatty acid composition of canola oil (NBD ID: 04582) is comprised of 7.37 g saturated fat/100 g of product, 63.28 g monounsaturated fat/100 g of product, 28.14 g polyunsaturated fat/100 g of product, and 0.40 g trans fat/100 g of product [51]. The major fatty acids that make up the fatty acid composition of canola oil are long chain fatty acids, specifically palmitic acid (C_{16:0}), stearic acid (C_{18:0}), oleic acid (C_{18:1}), linoleic acid (C_{18:2}), and linolenic acid (C_{18:3}).

The fatty acid composition of coconut oil (NBD ID: 04047) is comprised of 82.48 g saturated fat/100 g of product, 6.33 g monounsaturated fat/100 g of product, 1.07 g polyunsaturated fat/100 g of product, and 0.02 g trans fat/100 g of product [51]. The major fatty acids that make up the fatty acid composition of coconut oil are a combination of short, intermediate, and long chain fatty acids. Approximately 0.50 percent of fatty acids have less than 6 carbons, approximately 54 percent of fatty acids have 8–12 carbons, and approximately 55 percent of fatty acids have more than 14 carbons [51]. Specific fatty acids that are found in high quantities in coconut oil are caprylic acid (C_{8:0}), capric acid (C_{10:0}), lauric acid (C_{12:0}), myristic acid (C_{14:0}), palmitic acid (C_{16:0}), stearic acid (C_{18:0}), oleic acid (C_{18:1}), and linoleic acid (C_{18:2}).

The fatty acid composition of sunflower oil can differ greatly dependent on manufacture specifications. An example of the fatty acid composition of sunflower oil is a brand of sunflower found on the USDA Nutrient database (NBD ID: 45212857) that is comprised of 6.67 g saturated fat/100 g of product, 53.33 g monounsaturated fat/100 g of product, 26.67 g polyunsaturated fat/100 g of product, and 0.00 g trans fat/100 g of product [51]. The major fatty acids that make up the fatty acid composition of sunflower oil are long chain fatty acids, specifically palmitic acid (C_{16:0}), stearic acid (C_{18:0}), oleic acid (C_{18:1}), and linoleic acid (C_{18:2}).

The fatty acid composition of corn oil (NBD ID: 45287255) is comprised of 14.29 g saturated fat/100 g of product, 28.57 g monounsaturated fat/100 g of product, 57.14 g polyunsaturated fat/100 g of product, and 0.00 g trans fat/100 g of product [51]. The major fatty acids that make up the fatty acid composition of corn oil are a combination of intermediate and long chain fatty acids. Approximately 11 percent of fatty acids have 8–12 carbons and approximately 89 percent of fatty acids have more than 14 carbons [51]. Specific fatty acids that are found in high quantities in corn oil are caprylic acid (C_{8:0}), capric acid (C_{10:0}), myristic acid (C_{14:0}), palmitic acid (C_{16:0}), stearic acid (C_{18:0}), oleic acid (C_{18:1}), and linoleic acid (C_{18:2}).

Cocoa butter is not a typical ingredient found in meat analogue or processed meat products; however, cocoa butter is included in the most recent (as of September 2019) recipe for the Beyond burger. The fatty acid composition of cocoa butter (NBD ID: 04501) is comprised of 59.70 g saturated fat/100 g of product, 32.90 g monounsaturated fat/100 g of product, 3.00 g polyunsaturated fat/100 g of product, and 0.00 g trans fat/100 g of product [51]. The major fatty acids that make up the fatty acid composition of cocoa butter are long chain fatty acids. Specific fatty acids that are found in high quantities in cocoa butter are palmitic acid (C_{16:0}), stearic acid (C_{18:0}), and oleic acid (C_{18:1}).

The fatty acid composition of fats and oils is certainly variable between sources and manufacturing methods. It is possible, and actually very likely, that refinement techniques such as pressing, fractionation, and isomerization can alter the fatty acid composition of the plant-based fats and oils used in modern meat analogue products. However, utilizing what is known about the general composition of the fats and oils used in modern meat analogue products, the breakdown of fatty acids in terms of saturated vs. unsaturated fats in modern meat analogue products and traditional meat products is comparable. The greatest difference is the introduction of

short chain and intermediate chain saturated fatty acids with some of the plant oils that are used in meat analogue products, namely coconut oil and corn oil. Greater research is certainly warranted to determine if the incorporation of short and intermediate chain saturated fatty acids is a positive or negative in terms of nutritional health and wellness.

3.3. Carbohydrate ingredients

Meat does not contain carbohydrates, unless the meat product is further processed and carbohydrate ingredients are added, which is actually very common in meat processing especially in emulsified and formed processed meat products [55]. Meat analogue products on the other hand almost always contain carbohydrates. The carbohydrates found in meat analogue products can come from a variety of different ingredients and those ingredients can serve a variety of purposes in the manufacturing process. Carbohydrate ingredients can be categorized as the starches or flours used to improve product texture and consistency, or the binding ingredients or gums, like methylcellulose, acacia gum, xanthan gum, carrageenan, and many others, that are used to improve product stability and form [4,13,55]. Functionally speaking, the purposes of these ingredients are for improved interaction between the protein, lipid, and water components of the processed food system. In short these ingredients help catalyze these components and form a stable structure. From a nutritional standpoint, carbohydrates can be viewed as health enhancing in the form of greater dietary fiber or detrimental to health in the form of greater refined starches or sugars [56,57]. Generally, a combination of dietary fiber, starches, and sugars are included in the formulation of both meat analogue products and processed meat products [4,13,55]. Therefore, it is difficult to determine if there are actually health advantages in terms of the carbohydrate ingredients added to meat analogue products.

There is substantial speculation and debate on if the binders and gums included in meat analogue products and processed meat products are safe for consumers. One ingredient in particular is methylcellulose which is included in many modern meat analogue products; as well as, many other types of processed food products. Methylcellulose is a modified cellulose dietary fiber, and when included in appropriate quantities in food products is a very effective binder [58]. From a nutritional standpoint, methylcellulose generates a viscous solution in the gastrointestinal tract and has been shown to have similar effects on glucose metabolism when compared with other sources of dietary fiber [59–61]. Another type of ingredient that has elicited much debate regarding its nutritional health are the various types of gums (i.e. acacia gum, guar gum, xanthan gum, and others) used in the manufacture of meat analogue products, processed meat products, and other processed food products. With specific interest to the meat analogue products discussed in this review, ingredients like gum acacia, xanthan gum, and carrageenan are used in some modern meat analogues. These ingredients have been used in various food processing applications in the past, including processed meat products. The health and wellness of these products have been challenged, but no real health risks or concerns have been discovered [62,63]. With that said, the push from consumers for cleaner labels on food products has influenced food processors to limit or eliminate the use of these ingredients in many processed food products, including processed meat products [55,64].

3.4. Flavor enhancer

Specific flavor ingredients are added to meat analogue products in the form of seasonings and spices, just as they are in most processed and prepared foods. To achieve the “meat-like” flavor in meat analogues a variety of different techniques have been inves-

tigated. As Kyriakopoulou et al. (2019) describe in their review, the isolation of specific naturally-occurring volatile compounds, sometimes in combination with various thermal processing, is the primary methodology used to capture the flavor and aroma attributes of meat products [13]. These obtained flavor compounds are then incorporated into meat analogue formulations at appropriate levels after extensive testing is conducted.

3.5. Coloring agents

The color of meat products is often considered the most important attribute for consumer purchase intent [65,66]. In addition to the characteristic color of uncooked meat products (typically bright cherry red for beef, reddish pink for pork, and bluish-white to yellow for poultry), the color of meat products changes during cooking as the proteins responsible for the characteristic color of meat (primarily myoglobin) undergo chemical changes [66]. A similar concept could be presented for the importance of the color and the change of color during cooking for meat analogue products. Meat analogue products should have similar color attributes to the meat product they are simulating before, during, and after cooking [13]. The ingredients used in modern meat analogue products to achieve the characteristic colors vary from product to product. The general concept is formulation with ingredients that elicit naturally occurring color attributes that are comparable with the meat product being simulated. This is the case with the meat analogue product the Beyond burger which uses beet juice extract, and for the meat analogue product the MorningStar Farms burger that uses tomato paste. Another concept that is used to achieve color attributes similar to traditional meat products is the use sarcoplasmic proteins that have a similar chemical structure to the iron- and oxygen-binding protein found in muscle tissue, which is again the protein myoglobin. The meat analogue product the Gardein meatless meat balls uses a reduced iron compound, while the meat analogue product the Impossible burger uses soy leghemoglobin, which is a soy-derived compound with similar chemical and structural feature as hemoglobin and myoglobin, the former, again, being a major protein responsible for the color of meat. While the safety risks associated with soy leghemoglobin are still being explored, the studies that exist currently suggest there is no toxicological concern with the ingredient [67,68].

3.6. Processing techniques

While this review is not centered on the processing techniques used to manufacture meat analogues, it should be noted that this area of work is not yet fully developed and considerable advancement will likely be made here as the meat analogue marketplace expands and resources are expended on advancements in research and development. Of note, current production processes for meat analogues include techniques such as extrusion, spinning, and simple shear flow [3,4,13].

4. Nutrition of meat analogues

Meat analogues are formulated in a manner where the main priority of the manufacturer is to create a product with similar organoleptic properties of the targeted meat product, while meeting macro-nutrient specifications of the targeted meat product [3,4,13,38]. In terms of macro-nutrient specifications, the amount of protein is likely the first macro-nutrient of importance. From a nutritional and functional standpoint, it also makes sense to maintain similar levels of moisture and lipid. Therefore, in terms of a macro-nutrient standpoint, meat analogue products are similar to the traditional meat products they simulate (Table 2). The information provided in Table 2 was sourced from the publically available

Table 2
Nutritional composition of different food products – current as of September 2019.

| Product ^a | Energy value (kcal) | Protein (g) | Fat (g) | Saturated fat (g) | Cholesterol (mg) | Total carbohydrates (g) | Dietary fiber (g) | Na (mg) | Fe (mg) |
|---|---------------------|-------------|---------|-------------------|------------------|-------------------------|-------------------|---------|---------|
| Meat analogue products | | | | | | | | | |
| Beyond burger | 221.24 | 17.70 | 15.93 | 5.31 | 0.00 | 2.65 | 1.77 | 345.13 | 3.72 |
| Impossible burger | 212.39 | 16.81 | 12.39 | 7.08 | 0.00 | 7.96 | 2.65 | 327.43 | 3.72 |
| MorningStar farms grillers original burger | 203.13 | 25.00 | 7.81 | 0.78 | 0.00 | 12.50 | 6.25 | 609.38 | 1.72 |
| Boca all American veggie burger | 140.85 | 18.31 | 5.63 | 1.41 | 7.04 | 8.45 | 5.63 | 492.96 | 2.39 |
| Gardein meatless meat balls | 166.67 | 15.56 | 7.78 | 0.56 | 0.00 | 10.00 | 3.33 | 355.56 | 8.33 |
| Tofurky ham roast with glaze | 203.70 | 20.37 | 5.56 | 0.46 | 0.00 | 18.52 | 0.93 | 592.59 | 1.76 |
| Quorn brand chik'n nuggets | 203.39 | 10.17 | 8.47 | 0.42 | 6.78 | 24.58 | 5.93 | 449.15 | 0.72 |
| Traditional meat products | | | | | | | | | |
| Ground beef (93% lean, 7% fat), uncooked/raw | 152.00 | 20.85 | 7.00 | 2.89 | 63.00 | 0.00 | 0.00 | 66.00 | 2.33 |
| Ground beef (93% lean, 7% fat), cooked, pan-fried | 182.00 | 25.56 | 8.01 | 3.29 | 84.00 | 0.00 | 0.00 | 72.00 | 2.82 |
| McDonald's beef patty | 266.67 | 23.33 | 20.00 | 8.33 | 83.33 | 0.00 | 0.00 | 400.00 | 3.33 |
| Tyson fully cooked homestyle beef meatballs | 300.00 | 15.56 | 16.47 | 5.88 | 47.06 | 5.88 | 1.18 | 352.94 | 2.12 |
| Hormel cure 81 classic boneless ham | 105.95 | 18.45 | 3.57 | 1.19 | 50.95 | 0.24 | 0.00 | 1038.10 | 0.83 |
| Tyson fully cooked chicken nuggets | 300.00 | 15.56 | 18.89 | 4.44 | 44.44 | 16.67 | 0.00 | 522.22 | 0.91 |

^a All products are standardized to a 100 g serving.

information found on product labels and web pages of the selected products. The following section discusses the composition of nutrients, and will be broken down as a comparison between meat analogues and the traditional meat products being simulated by the meat analogues.

4.1. Beef burger products

Beef burger simulation products are at the forefront of modern meat analogue marketplace, with several of the most popular retail and food service products being represented in this category. To begin the characterization, nutrient values of cooked ground beef (93% lean, 7% fat) and the McDonald's beef patty are outlined as standards for traditional meat products. It is believed that these products accurately represent a retail beef product that was unseasoned and a fully prepared food service product that was seasoned during cooking, respectively. Cooked ground beef (93% lean, 7% fat) has the following nutrient specifications according to the USDA Nutrient Database [51]: 182.00 kcal/100 g, 25.56 g/100 g total protein, 8.01 g/100 g total fat, 3.29 g/100 g saturated fat, 84.00 mg/100 g cholesterol, no carbohydrates and no dietary fiber, 72.00 mg/100 g of sodium, and 2.82 mg/100 g of iron. The McDonald's beef patty has the following nutrient specifications: 266.67 kcal/100 g, 23.33 g/100 g total protein, 20.00 g/100 g total fat, 8.33 g/100 g saturated fat, 83.33 mg/100 g cholesterol, no carbohydrates and no dietary fiber, 400.00 mg/100 g of sodium, and 3.33 mg/100 g of iron. It is quite clear to see in the comparison of these two products that the McDonald's beef patty, a fully prepared and seasoned food service product, has a greater fat content indicated by both the total fat content and the saturated fat content, and that the grill seasoning used for preparation of the McDonald's beef patty increased the sodium content by approximately 5.5×, or 550%, compared with unprepared ground beef.

The four meat analogue products evaluated in this review that simulate beef burger products differed considerably in their nutrient composition but were in general similar to that of a fully prepared food service product (McDonald's beef patty). An interesting finding is that two of the modern meat analogue products (the Beyond burger and the Impossible burger) were similar to the McDonald's beef patty in total fat content (15.93 g/100 g and 12.39 g/100 g versus 20.00 g/100 g, respectively) and in saturated fat content (5.31 g/100 g and 7.08 g/100 g versus 8.33 g/100 g, respectively). At first the level of saturated fats may seem surprising for a product manufactured with plant-based ingredients, but an investigation of the fats and oils (i.e. coconut oil, cocoa butter, etc.) used in these products make these figures representative. Total carbohydrates and dietary fiber were, as expected, greater for the meat analogue products, which are primarily derived from the plant-based ingredients used in their formulations. There is a general consensus that increased dietary fiber has health benefits [69]; however, the addition of other carbohydrates (starches and sugars) must also be considered when discussing nutritional benefits. Another consideration here is the level of sodium in the meat analogue products, which ranged from 327.43–609.38 mg/100 g. This is particularly alarming as we are only evaluating the burger, or patty, in this case and not the other components of the sandwich (i.e. bun and condiments). Overall, it can be confidently concluded that beyond the potential benefits from greater dietary fiber, there are no other potential nutritional benefits in modern meat analogue products that simulate beef burgers when compared with traditional beef burgers on a macro-nutrient basis.

4.2. Beef meatball products

Two meatball products, one meat analogue product (Gardein meatless meat balls) and one traditional product (Tyson fully cooked homestyle meatballs), were used to form a compar-

ison of nutrient specifications for this evaluation. In terms of protein content, both products have the same value of 15.56 g/100 g. The meat analogue product had a lower energy value (166.67 kcal/100 g versus 300.00 kcal/100 g), a lower fat content (7.78 g/100 g versus 16.47 g/100 g), a lower saturated fat content (0.56 g/100 g versus 5.88 g/100 g), a lower cholesterol content (0.00 mg/100 g versus 47.06 mg/100 g), a greater value for total carbohydrates (10.00 g/100 g versus 5.88 g/100 g), a greater value for dietary fiber (3.33 g/100 g versus 1.18 g/100 g), a similar sodium content (355.56 mg/100 g versus 352.94 mg/100 g) and a much greater value for iron content (8.33 mg/100 g versus 2.12 mg/100 g) compared with the traditional meat product. Overall, it can be concluded that the meat analogue product (Gardein meatless meat balls) would likely be a healthier (lower calorie, lower fat, greater dietary fiber) option when compared with the traditional meat product (Tyson fully cooked homestyle meatballs).

4.3. Pork ham products

Two boneless ham products, one meat analogue product (Tofurky ham roast with glaze) and one traditional product (Hormel cure 81 classic boneless ham), were used to form a comparison of nutrient specifications. In terms of protein content, both products have similar protein content, which differed by less than two percentage units (20.37 g/100 g versus 18.45 g/100 g). The meat analogue product had a greater energy value (203.7 kcal/100 g versus 105.95 kcal/100 g), a greater fat content (5.56 g/100 g versus 3.57 g/100 g), a lower saturated fat content (0.46 g/100 g versus 1.19 g/100 g), a lower cholesterol content (0.00 mg/100 g versus 50.95 mg/100 g), a much greater value for total carbohydrates (18.52 g/100 g versus 0.24 g/100 g), a greater value for dietary fiber (0.93 g/100 g versus 0.00 g/100 g), a much lower sodium content (592.59 mg/100 g versus 1038.10 mg/100 g) and a greater value for iron (1.76 mg/100 g versus 0.83 mg/100 g) compared with the traditional meat product. Overall, it can be concluded that the meat analogue product (Tofurky ham roast with glaze) was a lower sodium option compared with the traditional meat product (Hormel cure 81 classic boneless ham); however, beyond this there are no other potential nutritional benefits in this product, especially after considering the level of non-dietary fiber carbohydrates in this product.

4.4. Chicken nugget products

Two chicken nugget products, one meat analogue product (Quorn brand chik'n nuggets) and one traditional product (Tyson fully cooked chicken nuggets), were used to form a comparison of nutrient specifications. The meat analogue product had a lower energy value (203.39 kcal/100 g versus 300.00 kcal/100 g), a lower protein value (10.17 g/100 g versus 15.56 g/100 g), a lower fat content (8.47 g/100 g versus 18.89 g/100 g), a lower saturated fat content (0.42 g/100 g versus 4.44 g/100 g), a lower cholesterol content (6.78 mg/100 g versus 44.44 mg/100 g), a greater value for total carbohydrates (24.58 g/100 g versus 16.67 g/100 g), a greater value for dietary fiber (5.93 g/100 g versus 0.00 g/100 g), a similar sodium content (449.15 mg/100 g versus 522.22 mg/100 g) and a similar value for iron (0.72 mg/100 g versus 0.91 mg/100 g) compared with the traditional meat product. Overall, it can be concluded that the meat analogue product (Quorn brand chik'n nuggets) would likely be a healthier (lower calorie, lower fat, greater dietary fiber) option when compared with the traditional meat product (Tyson fully cooked chicken nuggets), yet the protein content of the meat analogue product was much lower in value and should be a consideration.

4.5. Summary of nutritional composition

In summary, the evaluation of the nutritional composition, in terms of macro-nutrient composition and other readily available minerals on the labels of food products, between modern meat analogue products and traditional meat products leads to inconclusiveness on which is generally healthier. It depends on the product and on which ingredients are used in both the meat analogue and traditional meat products. One consideration that should be more clear is that there is not a one size fits all approach when discussing the nutritional composition of meat analogue products versus traditional meat products, and the consumer should take the initiative to investigate the nutritional differences in the two types of products.

5. Conclusion

As previously mentioned, the meat analogue industry has made tremendous strides in the last several years and is predicted to reach a size of USD\$21.23 billion globally by 2025 [22]. Predictions indicate that the marketplace will continue to mature and the products will improve in terms of their formulation and their nutritional application. While this review provided only a snapshot of the ingredients used to formulate modern meat analogue products and how the nutrition of these products compare with traditional meat products, the review does hopefully provide the framework for an unbiased assessment to be made. The overlying goal is that this review can be successfully used in present time by food manufacturers, dietitians, nutritionists, regulators, and most importantly consumers in efforts to make informed decisions regarding the claims of meat analogue products. Additionally, this review may be of use in the future (10+ years down the road) to evaluate the growth and development of the meat analogue industry.

Declaration of Competing Interest

The author declares no conflict of interest and no funding was provided for the preparation of this review article. It is the author's intention to come away as an unbiased reviewer of the topic and themes presented in this paper. Brand names appearing in this review article are for product identification purposes only and all information presented is available to the general public. No endorsement or criticism was intended, nor was endorsement or criticism implied of products not mentioned.

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