PERSPECTIVE

Perspective: Soy-based Meat and Dairy Alternatives, Despite Classification as Ultra-processed Foods, Deliver High-quality Nutrition on Par with Unprocessed or Minimally Processed Animal-based Counterparts

Mark Messina,[1] **John L Sievenpiper,**[2,3,4] **Patricia Williamson,**[5] **Jessica Kiel,**[6] **and John W Erdman, Jr**[7]

[1] Soy Nutrition Institute Global, Washington, DC, USA; [2] Departments of Nutritional Sciences and Medicine, Temerty Faculty of Medicine, University of Toronto, Toronto, Ontario, Canada; [3] Division of Endocrinology and Metabolism, Department of Medicine, St. Michael's Hospital, Toronto, Ontario, Canada; [4] Li Ka Shing Knowledge Institute, St. Michael's Hospital, Toronto, Ontario, Canada; [5] Scientific and Regulatory Affairs, Research and Development, Cargill, Wayzata, MN, USA; [6] Scientific and Clinical Affairs, Medifast, Inc., Baltimore, MD, USA; and [7] Department of Food Science and Human Nutrition, Division of Nutritional Sciences and Beckman Institute, University of Illinois at Urbana/Champaign, Urbana, IL, USA

ABSTRACT

In many non-Asian countries, soy is consumed via soy-based meat and dairy alternatives, in addition to the traditional Asian soyfoods, such as tofu and miso. Meat alternatives are typically made using concentrated sources of soy protein, such as soy protein isolate (SPI) and soy protein concentrate (SPC). Therefore, these products are classified as ultra-processed foods (UPFs; group 4) according to NOVA, an increasingly widely used food-classification system that classifies all foods into 1 of 4 groups according to the processing they undergo. Furthermore, most soymilks, even those made from whole soybeans, are also classified as UPFs because of the addition of sugars and emulsifiers. Increasingly, recommendations are being made to restrict the consumption of UPFs because their intake is associated with a variety of adverse health outcomes. Critics of UPFs argue these foods are unhealthful for a wide assortment of reasons. Explanations for the proposed adverse effects of UPFs include their high energy density, high glycemic index (GI), hyper-palatability, and low satiety potential. Claims have also been made that UPFs are not sustainably produced. However, this perspective argues that none of the criticisms of UPFs apply to soy-based meat and dairy alternatives when compared with their animal-based counterparts, beef and cow milk, which are classified as unprocessed or minimally processed foods (group 1). Classifying soy-based meat and dairy alternatives as UPFs may hinder their public acceptance, which could detrimentally affect personal and planetary health. In conclusion, the NOVA classification system is simplistic and does not adequately evaluate the nutritional attributes of meat and dairy alternatives based on soy. *Adv Nutr* 2022;13:726–738.

Statement of Significance: NOVA classifies soymilk and soy-based meat alternatives as ultra-processed foods (UPFs). However, criticisms of UPFs are not applicable to these foods when they are compared with their animal-based counterparts, which are classified as unprocessed or minimally processed foods. Admonitions against soymilk and soy-based meat alternatives based on their NOVA classification may dissuade consumers from consuming foods that offer health and environmental benefits.

Keywords: NOVA, soymilk, soy-based meat alternative, ultra-processed foods, glycemic index, satiety, hyper-palatability, sustainable

Introduction

Over the past decade, plant-based meats and plant-based milks have markedly increased in popularity (1) because of their health and environmental attributes, and concerns over animal welfare (2). With regard to the environment, Goldstein et al. (3) concluded that plant-based beef substitutes could substantially reduce US greenhouse gas emissions, water consumption, and agricultural land occupation. Although plant-based patties made from different combinations of grains and beans have long been traditional vegetarian fare, the newest generation of plant-based meats is specifically designed to approximate the aesthetic qualities (primarily

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texture, flavor, and appearance) and nutritional attributes of specific types of meat in order to appeal to a broader range of consumers (4).

Despite their increased popularity, and potential environmental advantages, plant-based meat alternatives and plant-based milks have been criticized for being "highly processed." In fact, according to the NOVA food-classification system, most plant-based meat alternatives (5, 6) and plant-based milks (7) are classified as ultra-processed foods (UPFs; group 4) (for a detailed description, see **Text Box 1**) (5). This system categorizes all foods and food products into 4 groups according to the extent and purpose of the industrial processing they undergo (5, 8). In contrast to plant-based meat alternatives and plant-based milks, their animal-based counterparts (beef and cow milk) are classified as unprocessed or minimally processed foods (group 1). UPFs are industrial food and drink formulations made of food-derived substances and additives, often containing little or no whole foods (9). In their recent editorial, Meyer and Taillie (10) noted with alarm the increase in and overall high intake of UPFs among US youth.

Text Box 1
The NOVA food-classification system

- Group 1: Unprocessed/minimally processed
    - No added ingredients (fruit, vegetables, nuts, grains, meat, milk)
- Group 2: Processed culinary ingredients
    - Oils, fats, butter, vinegars, sugar, and salt, eaten with group 1
- Group 3: Processed
    - Mix of groups 1 and 2 (chiefly for preservation)
    - Smoked and cured meats, cheeses, fresh bread, bacon, salted/sugared nuts, tinned fruit, beer and wine
- Group 4: Ultra-processed
    - Made with non-home ingredients
    - Chemicals, colorings, sweeteners, and preservatives
    - Industrial breads, cereals, sausage, dressings, snacks
    - High fat, sugar, and salt content is common

Classifying plant-based meat alternatives and plant-based milks as UPFs may slow their acceptance among consumers because, in most studies, UPFs are associated with an array of adverse health effects, including obesity, cardiovascular disease, and overall mortality (11). In fact, Wickramasinghe et al. (12) recently recommended restricting the marketing of plant-based meat and dairy substitutes because of their degree of processing. However, the American Society for Nutrition (ASN) maintains that "processed foods are nutritionally important to American diets because they contribute to food security, ensuring that sufficient food is available, and nutrition security, ensuring that food quality meets human nutrient needs" (13). The ASN also noted that food-processing techniques such as enrichment and fortification can add essential nutrients that might otherwise be in short supply and can alter food profiles to decrease components that may be overconsumed (13). Processing can also limit microbial contamination and reduce foodborne illness (14). In other words, processing can make foods more healthful.

The conflicting viewpoints on processed foods, and specifically plant-based meats and plant-based milks, present a confusing picture to consumers, especially health and environmentally conscious individuals who are concerned about animal welfare. This Perspective argues that maligning plant-based meats and plant-based milks because of the processing they undergo is nutritionally unjustified and counterproductive to achieving the health and environmental goals of the WHO, as well as those of other health authorities and organizations (15–18). Note that several

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Address correspondence to MM (e-mail: markjohnmessina@gmail.com).

Abbreviations used: CVD, cardiovascular disease; DIAAS, digestible indispensable amino acid score; GHGE, greenhouse gas emissions; GI, glycemic index; GL, glycemic load; GWP, global warming potential; HPWL, high-protein, weight-loss; IAA, indispensable amino acid; PDCAAS, protein digestibility corrected amino acid score; SPC, soy protein concentrate; SPI, soy protein isolate; UPF, ultra-processed food.

authors have provided detailed overall critiques of the NOVA food-classification system (19–24). Therefore, the intent of this Perspective is not to critique the NOVA system in general. Nor is it to argue for reclassifying plant-based meat alternatives or plant-based milks. Rather, it is to show that, despite their classification as UPFs, these foods compare well with their animal-based counterparts, which are classified as unprocessed or minimally processed foods.

Although this Perspective discusses plant-based meat alternatives and plant-based milks in general, for 2 reasons, emphasis is placed on soymilk and soy-based meat substitutes. One, because of the large acreage devoted to growing soybeans, this legume has the greatest potential for meeting the caloric and protein needs of a growing global population. Approximately 350 million metric tons of soybeans are produced annually, and although most of that is used for animal feed (∼95%), its use is dictated by consumer demands (25).

Two, soy protein has traditionally been viewed by researchers as the reference plant protein, in part because of its high quality, and for this reason, is often compared with animal proteins, such as casein. Consequently, compared with other concentrated plant proteins, extensive clinical research has been conducted on concentrated sources of soy protein, which are the primary protein sources used in the manufacture of plant-based meat alternatives (26). For example, the ability of soy protein to lower blood cholesterol concentrations has been studied clinically for more than 50 y (27). Meta-analyses (28–35) published over the past nearly 20 y indicate a reduction in LDL cholesterol, ranging from 3.2% (35) to 6% (32). The impact of soy protein on muscle protein synthesis (36–38) and gains in muscle mass and strength (39) have also been widely studied. To this point, the results of a recent meta-analysis of longer-term studies (6–36 wk in duration) found that soy protein supplementation performed as well as whey and animal protein supplementation in individuals engaged in resistance exercise training (39).

Overview of Plant-based Meat Alternatives and Plant-based Milks

Role in meal planning

Many authors have recommended a shift toward a plant-based diet (15, 40–43), although the emphasis is typically on the consumption of whole foods or minimally processed foods, including whole grains, fruits, vegetables, nuts, legumes, and healthy oils (12). However, while these foods are nutritionally desirable, they are unlikely to fully address the orosensory preferences and practical needs of most consumers.

Legumes are an inexpensive, nutrient-rich source of protein (44), the consumption of which is recommended by health authorities throughout the world (45–48). Even so, legumes play a small role in the diets of developed countries and their intake is not expected to increase in the coming years in any region in the world (49). Furthermore, because pulses (grain legumes) are not an important part of Western diets, they require some education about how to cook and prepare them and how to incorporate them into recipes (50). As noted by van der Weele et al. (51), pulses are not novel from either a societal or technological point of view, and they have an unfavorable reputation as being old-fashioned.

In contrast to legumes, meat intake is expected to markedly increase over the next 30 y in many developing regions (52, 53). Therefore, plant-based meat alternatives that imitate many of the properties of meat are more likely to impact consumption trends, and thus address environmental concerns, than is the direct consumption of legumes and beans. Research indicates that, while vegetarian and vegan consumers will accept plant-based meat alternatives that lack meat-like sensory properties, omnivorous and flexitarian consumers prefer alternatives that resemble animal-based protein as much as possible (54–57). In contrast, a recent UK survey found that most meat-eaters agree with the ethical and environmental arguments for vegetarianism/veganism but do not follow these diets because of practical reasons relating to taste, price, and convenience (58).

Detzel et al. (59) noted that, despite being highly processed, high-quality, plant-based, protein-rich foods can help reduce the environmental impact of food consumption while appealing to potential user groups beyond dedicated vegetarians and vegans. Furthermore, according to Lonkila and Kaljonen (60), consumers want convenient products that are easy to use and cook, attributes that are associated with meat and milk. Plant-based meat alternatives and plant-based milks are designed to meet these consumer preferences and can easily substitute for animal protein without requiring modification of meal patterns or food habits (61, 62).

Also, because animal products, and especially meat, play an important role in structuring meals (62, 63), plant-based substitutes that have the same functional properties allow an easy transition from animal-based to plant-based diets (64). Other alternative protein sources such as cultured meat, algae, and insects require more technological change than plant proteins, as well as requiring more social-institutional change for their acceptance (51). According to Hoek et al. (65), replacement of meat is most likely to be achieved by significantly improving the sensory quality of meat substitutes, but decreasing the cost and increasing the availability of these products are also important for greater consumer acceptance (66).

Finally, evidence suggests that the food environment is an important determinant of food consumption (67, 68) and that certain eating context patterns, such as eating alone or eating while watching television, may promote the consumption of UPFs (69, 70). Since plant-based meats and plant-based milks are designed to be used in the same way as their animal-based counterparts, the food environment does not favor 1 type (animal or plant) of milk or meat over the other.

Nutritional implications

Recent research has addressed calls to gain a better understanding of the nutritional and health implications of plant-based substitutes, especially when replacing meat and dairy products (12). For example, Salomé et al. (61) assessed the effects of plant-based substitutes on the nutritional quality of the French diet by simulating separately the replacement of meat, milk, and dairy desserts with 96 plant-based substitutes. These authors found that overall plant-based substitutes had small and heterogeneous effects on diet quality and nutrient security, although plant-based substitutes that include legumes, such as soy, were shown to be more nutritionally adequate substitutes for animal products than other plant-based substitutes (61).

These overall findings align with the conclusion of Bohrer (71), that modern meat analogues can offer roughly the same composition of nutrients as traditional meat products. Similarly, Farsi et al. (72) concluded that plant-based meat alternatives can be a healthful replacement for meat, but also emphasized the need to choose options that are low in sodium and sugar, and high in fiber, protein, and nutrient density. From a protein perspective, these authors recommended choosing soy-based and mycoprotein-based (protein derived from fungi for human consumption) meat alternatives, but also noted the high sodium content of soy-based alternatives.

More in-depth analysis comes from van Vliet et al. (73), who found that, despite similarities based on front-of-package nutrition information, metabolomic profile abundances between a soy-based meat alternative (18 samples of the same product) and grass-fed ground beef (18 samples) differed by 90% (171 out of 190 profiled compounds; $P < 0.05$). However, the impact, if any, of these differences on the health status of the individuals consuming these products was not determined. Furthermore, all foods have vastly different metabolic profiles, including even those within the same botanical group (74, 75).

Direct experimental insight about health outcomes comes from Crimarco et al. (76), who compared the effect on nutrient intake and cardiovascular disease (CVD) markers of consuming ∼2.5 servings/d of plant-based meat (pea- and soy protein-based) with meat-based counterparts over an 8-wk period. In response to the plant-based meats, concentrations of LDL cholesterol (77) and trimethylamine-N-oxide (78), a proposed but not established CVD risk factor (79), were statistically significantly reduced. In terms of nutrient intake, there were no differences in sodium or protein intake, whereas in response to the consumption of plant-based products, saturated fat was lower and fiber intake higher, although the fiber difference was not statistically significant. More recently, the replacement of ∼5 servings/wk of meat with plant-based meat alternatives led to favorable changes (e.g., an increase in butyrate-metabolizing potential and a decrease in the *Tenericutes* phylum) in the gut microbiome over a 4-wk period (80).

Soy protein quality

Until recently, most of the research aimed at determining the quality of soy protein focused on the soy protein ingredients rather than traditional Asian soyfoods. The soy protein ingredients, soy protein isolate (SPI), soy protein concentrate (SPC), and soy flour, are composed of ≥90%, 65–90%, and 50–65% protein, respectively (26). An advantage of these concentrated sources of soy protein is that they more easily allow greater amounts of protein to be incorporated into experimental diets, especially into products such as beverages or baked goods (e.g., muffins) that can be made indistinguishable from products containing the control protein. This enables better participant blinding and enhanced compliance.

The high quality of soy protein was firmly established by a series of nitrogen balance studies by Young and colleagues conducted in the early 1980s (81–86). In the early 1990s, the protein digestibility corrected amino acid score (PDCAAS) was adopted by the US FDA and FAO as the method of choice for determining protein quality. Utilizing 2 different laboratories, Hughes et al. (87) determined that the untruncated PDCAAS of 3 different SPIs ranged from 0.95 to 1.02 and the scores for the single SPC were 1.02 and 1.05. These values are similar to those determined by Rutherfurd et al. (88) for SPI and by Mathai et al. (89) for SPI and soy flour. According to the USDA, to qualify as a high-quality protein requires a score of at least 0.8.

In 2011, an FAO consultation recommended transitioning from the PDCAAS to the digestible indispensable amino acid score (DIAAS) (90). Given that some methodological issues remain to be resolved (91), it will likely be several years before the DIAAS is accepted by regulatory bodies. Preliminary data using the DIAAS also support the high quality of soy protein (88, 89), although, in general, the quality of plant protein is rated slightly lower using this method compared with the PDCAAS (88). Very recently, Fanelli et al. (92) determined that the DIAAS for the Impossible Burger [(Impossible Foods) primary protein source is soy] was similar to the DIAAS for 80% ground beef when calculated using the indispensable amino acid (IAA) pattern for the older child, adolescent, and adult.

Applicability of criticisms of processed foods to soy-based meats and soymilk

As previously noted, the consumption of UPFs has been associated with a range of adverse health outcomes (11). Diets high in UPFs are associated with poor diet quality (93), but there is debate about the extent to which diet quality accounts for the associations between UPF intake and adverse health outcomes (19, 94). Many of the effects of processing will be identified by existing food-classification systems (nutritional rating systems) that are based exclusively on nutrient (and fiber) content. This is true for several of the major criticisms of UPFs, such as their high energy density (95, 96), high glycemic index (GI) (97) or high glycemic glucose equivalent (98), hyper-palatability (95), and low satiety potential (97). However, as noted by others, processing can lead to textural

TABLE 1 Nutrient, caloric, and fiber content of lean beef and selected soy-based burgers[1]

	Soy-based burgers					
Nutrient	Incogmeato (Morningstar Farms) (173)	Impossible (Impossible Foods) (174)	Boca vegan (Boca Foods Company) (175)	Gardein (Conagra Brands Pinnacle Foods) (176)	Morningstar Vegan (Morningstar Farms) (177)	Beef 80% lean, raw (178)
Serving size, g	120	113	71	85	113	113
kcal	280	240	70	130	270	287
kcal/g	2.33	2.12	0.99	1.50	2.39	2.50
Protein, g	21	19	13	14	27	19
Protein, % kcal	33.6	31.7	74.3	43.1	38.6	27.0
Fat, g	18	14	1	5.0	18	23
Fat, % kcal	64.8	52.5	12.9	52.9	57.9	70.9
Saturated fat, g	5.0	8.0	0	0	2.5	8.6
Saturated fat, % kcal	18	17	0	0	8	27
Carbohydrate, g	12	9	6	8	8	0
Carbohydrate, % kcal	19.2	15.0	34.3	24.6	11.4	0
Fiber, g	8	3	4	2	4	0
Vitamins, μg						
B-6	NI	0.34	NI	NI	NI	365
B-12	2.4	3.1	NI	NI	NI	2.4
Minerals						
Iron, mg	4.0	4.2	1.8	1.6	1.9	2.2
Zinc, mg	NI	5.5	NI[1]	NI	NI	4.7
Selenium, μg	NI	NI	NI	NI	NI	17
Potassium, mg	620	610	NI	240	180	305
Sodium, mg	370	370	450	340	580	66

[1] NI, not indicated.

and structural changes to the food matrix not identified by nutritional rating systems that can speed up the rate at which UPFs are consumed (96, 99, 100). Reducing the orosensory exposure time of a food can delay the onset of satiation (101). UPFs have been shown to be less satiating than minimally processed foods (97, 102), which can promote increased energy intake (103).

Energy intake rate may be an especially important contributor to the links between UPF intake and obesity. Forde et al. (100) recently showed, after pooling data from 5 studies that measured energy intake rates across a total sample of 327 foods, that when going from unprocessed, to processed, to ultra-processed, the average energy intake rate increased from 35.5 ± 4.4 to 53.7 ± 4.3 to 69.4 ± 3.1 kcal/min ($P < 0.05$), respectively. Additional explanations for the harmful effects of UPFs include the presence of artificial food additives (104–106) and artificial sweeteners, which have been linked to alterations to the gut microbiota (106–108), although not reliably in humans (109, 110). Also, food processing, and particularly heat treatment, may produce contaminants (e.g., acrylamide) in UPFs that may increase cancer risk (111). Bisphenol A, a contaminant suspected of migrating from plastic packaging of UPFs, has been shown to possess endocrine-disruptive properties (112).

Finally, although not related to personal health, claims have also been made that UPFs are not sustainably produced (9, 113), which is likely to become an increasingly important consideration in the formulation of dietary guidelines. According to the Society for Nutrition Education "environmental sustainability should be inherent in dietary guidance, whether working with individuals or groups about their dietary choices or in setting national dietary guidance" (114).

There are a variety of soy-based meat alternatives and soymilks on the market. For the examination of the applicability of the criticisms of UPFs to soy-based meat alternatives and soymilk, 5 soy protein–based burgers were compared with 80% lean beef (**Table 1**) and 2 soymilks were compared with whole and 2% cow milk, the 2 most commonly consumed milks in the United States (**Table 2**). Silk Original Soymilk and Silk Organic Unsweetened Soymilk were chosen for comparison because these products are the top 2 selling stock-keeping units in the US refrigerated soy plant-based beverage category. Silk is the leading brand based on US national sales data (Kristie Leigh, Danone North American, personal communication September 10, 2021).

Energy density

The connection between energy density, UPF intake, and weight gain was highlighted by a recent 2-wk crossover study involving 20 overweight adults (96). When consuming the diet composed primarily of UPFs, participants gained weight, whereas weight was lost during the unprocessed diet phase. The much higher nonbeverage energy density (2.147 vs. 1.151 kcal/g) of the UPF diet was suggested

TABLE 2 Nutrient, caloric, and fiber content of cow milk and soy milk[1]

	Cow milk		Silk	
Nutrient	**Whole (179)**	**Reduced-fat (180)**	**Original (181)**	**Organic unsweetened (182)**
Serving size, mL	240	240	240	240
Total energy, kcal/serving	149	122	110	80
kcal/mL	0.62	0.51	0.46	0.33
Protein, g	7.7	8.1	8.0	7.0
Protein, % kcal	20.6	26.4	29.0	35.0
Fat, g	7.9	4.8	4.5	4.0
Fat, % kcal	47.9	35.6	36.4	45.0
Saturated fat, g	4.63	3.07	0.50	0.50
Saturated fat, % kcal	28.0	22.6	4.1	5.6
Carbohydrate, g	11.7	11.7	9.0	3.0
Carbohydrate, % kcal	31.4	38.4	32.7	15.0
Sugars	12.3	12.2	6.0	1.0
Fiber	0	0	2	2
Vitamins				
Riboflavin, μg	412	451	400	400
Folate, μg	12.2	12.2	40.0	50.0
Thiamin, μg	112	95	NI	NI
Niacin, μg	217	224	NI	NI
Vitamin B-6, μg	88	93	NI	NI
Vitamin B-12, μg	1.3	1.3	3.0	3.0
Vitamin A, RAE	112	134	150	150
Vitamin D, μg	3.2	2.9	3.0	3.0
Minerals				
Calcium, mg	276	293	450	300
Potassium, mg	322	342	380	350
Magnesium, mg	24.4	26.8	50.0	40.0
Phosphorus, mg	205	224	220	80
Iron, mg	0.07	0	1.30	1.00
Zinc, mg	0.90	1.17	NI	NI
Iodine, μg	NI	NI	NI	NI
Sodium, mg	105	115	90	75

[1] NI, not indicated; RAE, retinol activity equivalents.

as being a key factor contributing to the weight gain. The energy density (kilocalories/gram) of the soy burgers in Table 1 is similar to or lower than that of beef. On a percentage calorie basis, the soy-based burgers contain similar or higher amounts of protein, but similar or lower amounts of fat and, unlike the beef, contain dietary fiber. It is reasonable to speculate that the fiber content of soy-based burgers could promote satiety relative to beef (115). Therefore, there is little reason to suggest the eating rate (grams/minute) or, more importantly, the energy intake rate (kilocalories/minute) of the soy burgers would be greater than beef. The soy-based burgers do contain carbohydrate, although much of that is fiber. As somewhat of an aside, although only one of the soy-based burgers qualifies as a high-sodium food (≥460 mg/serving), 2 others come close to doing so. Therefore, manufacturers of soy-based meat alternatives should be encouraged to keep sodium content in mind when producing new, or reformulating, products.

Table 2 shows that the soymilks have a lower energy density than both whole and 2% cow milk and contain similar amounts of protein. The major difference between milk types is with respect to carbohydrate content: the soymilks contain fiber (2 g/serving) and sucrose, whereas cow milk has no fiber and contains lactose. However, the soymilks contain a lower percentage of calories from carbohydrate and are lower in sugar. Neither the energy density nor macronutrient content suggests that soymilk would result in a faster eating rate or greater energy intake rate than cow milk. Although not necessarily related to satiety, it is notable from an overall health perspective that, as a percentage of calories, the soymilks and soy burgers are lower in saturated fat than their animal-based counterparts.

Glycemic response

There is convincing evidence that reducing postprandial glycemia is a desirable physiological goal (116, 117) and that doing so reduces the risk of developing diabetes (118, 119) and coronary artery disease (120). As noted, the impact of processing on the GI has been highlighted as a factor possibly contributing to the adverse health outcomes associated with UPF intake (97). Processing can affect the GI of foods (121–123) even independently of fiber content (124).

The American Diabetes Association recommends consumption of low (<55) and medium (56–69) GI foods for people with diabetes and other individuals looking to control blood sugar concentrations. Both soymilk and cow milk are acceptable foods according to these criteria (125). The GI and the glycemic load (GL; a measure that combines the GI with the amount of carbohydrate in a food) of soymilks depend upon the amount of added sugar (126).

Serrano et al. (127) concluded that soymilk was a low-GI food based on the results of a crossover study in which 29 young adults ingested 500 mL water, 500 mL glucose solution (20.5 g/500 mL), or 500 mL of soymilk on 3 separate occasions. Sun et al. (128) found that, in Chinese participants, coingestion of cow milk or soymilk with bread lowered the postprandial blood glucose response relative to bread alone. Also, Law et al. (129) found no difference between the effect of cow milk and soymilk on blood glucose or insulin concentrations at 180 min after consuming a meal that, in addition to each milk, contained bread and jam (cow milk was 2% fat and the soymilk was made using SPI). Finally, Atkinson et al. (121) reported that the GIs of cow milk (full-fat) and soymilk were 39 and 34, respectively, although more recent work from this group reported an average GI of only 25 for 13 different cow milks of variable fat content (130). The evidence overall suggests that there is nothing inherent to soymilk that would cause it to have a higher GI or GL than cow milk.

Hyper-palatability/satiety

Preliminary research indicates that many UPFs that are often high in fat and have a high GL are hyper-palatable and linked to addictive-like eating behaviors (131, 132). However, recent research shows that UPFs are not in and of themselves hyper-palatable (133). Furthermore, and more importantly, research shows that soymilk is not viewed as hyper-palatable in comparison to cow milk (134–138). With regard to meat, from a sensory perspective, it is the gold standard that the new generation of plant-based meat alternatives is trying to emulate (as opposed to a black bean burger, which is not designed to mimic the taste of meat) (4). While this standard may be matched, it is not clear how it could be exceeded, a conclusion that aligns with recent survey results (139).

As noted previously, one concern about UPFs is that their physical and structural characteristics may result in lower satiety potential and higher glycemic response (97) and may, because of their higher energy density, be consumed at a faster energy intake rate than less-processed foods (96). These attributes could lead to an increased energy intake, which, in turn, could lead to obesity and associated adverse health outcomes. However, evidence indicates that these concerns do not apply to soy-based meats or soymilk.

No clinical studies were identified that compared the effects of a soy-based burgers with meat, or soymilk with cow milk, on weight loss. However, in the Study With Appetizing Plantfood-Meat Eating Alternative Trial (SWAP-MEAT), weight loss occurred in the group consuming plant-based meat alternatives, some of which were based on pea protein and some on soy protein (76). Therefore, at the very least, the results indicate that plant-based meats are not inherently obesogenic. Also, meal replacements containing isolated proteins led to greater weight loss than traditional weight-loss diets (140–142), which suggests that, at the least, concentrated sources of proteins such as SPI and SPC do not promote weight gain.

Two studies compared beef and products made with soy protein ingredients on metabolic parameters related to weight loss. In one, obese participants consumed either a vegetarian (soy) high-protein, weight-loss (HPWL) diet or a meat-based HPWL for 2 wk and then crossed over to the opposite diet (143). Assessments of appetite control, weight loss, and gut hormone profile (glucagon like peptide 1, ghrelin, and peptide YY) did not differ between the diets. The soy-HPWL and meat-HPWL diets were each composed of 30% protein, 30% fat, and 40% carbohydrate. The meat-HPWL diet was based on chicken and beef; the soy-HPWL diet was based on soy protein ingredients. In the other study, meals (400 kcal) containing beef or SPC were matched for macronutrients and fiber or serving size (2 different arms) and consumed by 21 young, healthy adults (144). The type of protein consumed within a mixed meal had little effect on appetite, satiety, or food intake.

Finally, a study in 96 healthy adults found no difference between the mean (±SD) chewing time associated with 5 g chicken (16.9 ± 5.6 s) and 5 g vegetarian (soy-based) chicken (17.9 ± 6.2 s), although the former resulted in a bolus of chicken that had significantly more ($P < 0.001$) and smaller ($P < 0.001$) particles than vegetarian chicken (145). The similar chewing time suggests that energy intake rate is not likely to differ between meat and soy-based meat alternatives.

Sustainability

As noted earlier, claims have been made that UPFs are not sustainably produced (9, 113), which is likely to become an increasingly important consideration in the formulation of dietary guidelines (114). As discussed below, evidence indicates that soy-based meat and dairy products have environmental advantages. However, it is important to acknowledge that, as is the case for the impact of diet on health, there are widely differing opinions about the effects of diet on climate and its potential to affect global warming (146, 147). Establishing the global warming potential (GWP) of a dietary pattern or food is a complex process that involves a scientific understanding that continues to evolve. The environmental impact of any food, whether it be soymilk or soy-based meat, will depend, in part, upon the specific composition of the product in question.

Legumes have been shown to have an extremely low GWP, in comparison to nearly all other protein sources (148–151), although this depends in part upon the management of the agro-ecosystem used (e.g., mono-cropping vs. conservation agriculture) (152). In 2011, González et al. (153) determined that, of the 22 plant and animal protein sources evaluated, soybeans were the most efficiently produced and provided the most protein (grams) per greenhouse gas emissions

[GHGE; kilogram carbon dioxide (kg CO_2) equivalents]. Tessari et al. (154) emphasized that, when considering the environmental impact of foods, it is important to consider nutritional value and, in particular, IAA content. When this metric was used, there was little difference between animal and plant protein sources, except for soybeans, which exhibited the smallest environmental footprint.

Soybeans, like all legumes, can fix nitrogen because of the bacterial symbionts (rhizobia) that inhabit nodules on their roots. The amount of ammonia produced by rhizobial fixation of nitrogen by legumes rivals that of the world's entire fertilizer industry (155). The fact that legumes do not require nitrogen fertilizer for growth represents an important environmental advantage because half the nitrogen applied to fields for crop fertilization is thought to be lost into the environment, creating environmental concerns due to entry in surface and groundwater (156, 157).

While the environmental impact of soybean production is an important consideration, it is only 1 factor affecting the environmental impact of soy protein ingredients and the products made using them. Therefore, the conclusion by van Mierlo et al. (158) that soy protein ingredients are keys to mimicking the nutrient profile of meat, while minimizing environmental impact with regard to climate change, land use, water use, and fossil fuel depletion, is notable. This conclusion agrees with work by Thrane et al. (159). Reducing water and land use is particularly notable. Several groups have determined that the GWP of meat alternatives is lower than that of meat (3, 160–164). For example, the GWP of an Impossible Burger was determined to be lower than that of a beef burger and to require less land and water for its production (165).

With respect to soymilk, research has shown that its production requires considerably less water than to produce cow milk (166, 167). Also, shelf-stable soymilk was found to produce far fewer GHGE than shelf-stable cow milk (168). In agreement, Poore and Nemecek (148) found that, for each of the 5 criteria considered (GHGE, land use, acidification, eutrophication, water scarcity), and when expressed on a per-protein basis, soymilk production always resulted in a lower environmental impact than cow milk. Very recently, Coluccia et al. (169) also concluded that soymilk has a lower carbon footprint than cow milk.

Summary and Conclusions

The increased role of plant-based meat alternatives and plant-based milks in the diets of consumers around the world necessitates that scientists and health professionals have a detailed understanding of their nutritional, health, and environmental attributes, and considerable progress in this regard has been made. Nevertheless, plant-based products have been criticized for being overly processed (12). While it is undoubtedly true that many UPFs are not nutrient dense (170, 171), it is important not to assume that "ultra-processed" equals poor nutritional quality, since quality does not depend solely on the intensity or complexity of processing but on the final composition of the food itself (172).

As discussed, soy-based meats and soymilk compare favorably with their animal-based counterparts nutritionally. Further, there is no evidence that the major criticisms of UPFs [including high energy density (95, 96), high GI (97), hyper-palatability (95), and low satiety potential (97)] apply to these soy-based products. Certainly, within each category of plant-based meat alternatives and plant-based milks there will be variations in nutrient content because of differences in the protein source, fat source, and the extent of fortification. Therefore, consumers will need to compare Nutrition Facts panels. Consumers are best advised to choose soymilks that are protein-rich (6–8 g/cup), low in sugar, and that are fortified with calcium and vitamin D, and to keep sodium content in mind when choosing plant-based meats. However, admonitions against the consumption of products simply because they are classified as UPFs are unwarranted and may impair society's acceptance of plant-based diets—thus preventing the related health and environmental advantages from being realized.

While it may be true that the consumption of many UPFs should be discouraged based on nutrient content, this generalization does not apply to all such foods. Rather, the nutritional composition of the final product and its impact on health and sustainability should serve as the ultimate guide concerning the merits of a specific food, not the extent to which that food is considered processed. In summary, in the case of soy-based meat alternatives and soymilks, the NOVA classification system is overly simplistic and of little utility for evaluating the true nutritional attributes of these foods.

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