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RE: FDA-2023-D-0451: Labeling of Plant-Based Milk Alternatives and Voluntary Nutrient Statements; Draft Guidance for Industry

The Good Food Institute (GFI) appreciates the opportunity to comment on the important issue of labeling plant-based milks. GFI is a nonprofit think tank and open-access resource hub developing the roadmap for a sustainable, secure, and just protein supply. GFI's team of scientists, entrepreneurs, and policy experts supports research and innovation in alternative proteins—including plant-based foods—to meet consumer demand and feed a growing world. GFI also supports fair public policy that places conventional and alternative proteins on a level playing field.

FDA's draft guidance will have a substantial impact on the plant-based milk industry and on consumer choice. GFI urges FDA to treat plant-based milks fairly and avoid any labeling scheme that would unfairly burden one class of products in the marketplace.

The draft guidance, for the most part, sets forth a clear naming scheme for plant-based milks that acknowledges the common or usual name for these products, recognizes that consumers are not confused by plant-based milk labeling, and aligns with First Amendment jurisprudence. However, FDA's statements about exercising enforcement discretion with respect to the "imitation" food provision of the federal Food Drug & Cosmetic Act (FDCA) muddies the waters and contravenes the agency's otherwise clear guidance on naming plant-based milks. Furthermore, the nutrient labeling scheme proposed in the guidance is overbroad, unfair, and has the potential to cause consumer confusion. We provide more detailed feedback on these aspects of the draft guidance below.

Nomenclature

GFI applauds FDA's recognition that consumers understand the difference between plant-based milk and cow's milk and that shoppers choose to purchase plant-based milk specifically *because* it is not cow's milk. FDA also acknowledges that consumers choose plant-based milks for a variety of reasons, including allergies and lactose intolerance, as well as religious and ethical reasons. Furthermore, the draft guidance accurately concludes that plant-based milks that use the term "milk" in their names do not purport to contain cow's milk, that common or usual names have been established for plant-based milks (e.g., "soy milk" and "almond milk"), and that consumers do not believe that plant-based milks contain cow's milk. FDA also found that consumers prefer the term "milk" when referring to these plant-based products, over terms like "beverage" or "drink."

Given these facts, the only logical conclusion is that the use of the term "milk" in the names of plant-based milk products is not only truthful but also helpful to consumers and not misleading, so long as the names also clearly indicate that the product is plant-based.[1] The nomenclature scheme set forth in the draft guidance is clear and logical and will allow consumers to continue to choose between a variety of plant-based and cow's milk products that suit their needs. FDA should consider, however, allowing plant-based milks that are derived from multiple plant sources to use a qualifier such as "plant-based," or another simple and direct name, rather than requiring the inclusion of each plant source. While the common or usual name for single-source milks like almond milk and soy milk includes the name of the plant source, this is not likely the case for products with multiple plant sources. Some innovative products contain more than two or three plant sources, and requiring all of these sources to be included in the product name will become cumbersome and may disadvantage these products compared to those with short and

[1] In 2017, GFI submitted a citizen petition to FDA, titled Petition to Recognize the Use of Well-Established Common and Usual Compound Nomenclatures for Food (Docket No. FDA-2017-P-1298) (3/2/17) (supplemented on August 29, 2017 and March 20, 2020). The petition proposes that FDA issue a regulation clarifying that foods may be named by reference to the names of other foods, including standardized foods, so long as the name of the referenced food is qualified in a way that appropriately conveys the nature of the food at issue. FDA's decision to allow the use of the term "milk" along with an appropriate qualifier on plant-based milk product labels is directly aligned with this proposed regulation. Accordingly, GFI respectfully requests that FDA grant its citizen petition at this time.

easy-to-read names. Furthermore, consumers can look to the ingredients list to understand the plant sources and other ingredients in these products.

FDA has a history of permitting products with multiple plant ingredients to use a shorter name that summarizes their contents, rather than requiring every primary plant ingredient to be included in the statement of identity. For example, FDA's regulation on labeling fruit and vegetable juices allows a beverage containing multiple juices to be named using the name of one juice ingredient along with the term "blend" to indicate that the beverage is not made from a single fruit or vegetable.[2] Similarly, multiple products on the market use the name "veggie burger" or "veggie patty." These products are often made up of a number of vegetables, such as soybeans, peas, beans, lentils, mushrooms, sweet potatoes, and carrots, along with other ingredients like nuts and grains. FDA has not directed that these products be renamed to include the names of any of the vegetables they contain. Consumers understand that "veggie burger" is an umbrella term and that they can look to the ingredient list to understand exactly which vegetables are in each product. These naming schemes make sense, given that FDA regulations require the common or usual name of a food to state "in as simple and direct terms as possible, the basic nature of the food."[3] A similar approach would logically apply to plant-based milks with multiple plant sources and would be much easier for consumers to quickly read and understand compared to a lengthy compound name that lists multiple plant sources. For these reasons, FDA should consider other options for products containing more than two plant sources, consistent with prior agency practice.

Finally, GFI recognizes that cow's milk producers may oppose the nomenclature scheme set forth in the guidance because it establishes a level playing field on which plant-based milk can succeed in the marketplace.[4] GFI urges FDA not to alter the proposed nomenclature scheme in order to protect the dairy industry at the expense of the plant-based industry. Consumers have the

[2] 21 CFR § 102.33(c) ("If a diluted multiple-juice beverage or blend of single-strength juices contains a juice that is named or implied on the label or labeling other than in the ingredient statement (represented juice), and also contains a juice other than the named or implied juice (nonrepresented juice), then the common or usual name for the product shall indicate that the represented juice is not the only juice present (e.g., 'Apple blend; apple juice in a blend of two other fruit juices.')."

[3] 21 C.F.R. § 102.5(a).

[4] Although the conventional dairy industry has dedicated significant resources to fighting the emergence of plant-based milks, retail data indicates there is room for both plant-based and cow's milk in the market. The vast majority of households that purchase plant-based milk also purchase cow's milk. Having plant-based options available simply gives consumers greater choice. *See* U.S. Department of Agriculture, *Plant-Based Products Replacing Cow's Milk, But the Impact is Small*, https://www.ers.usda.gov/amber-waves/2020/december/plant-based-products-replacing-cow-s-milk-but-the-impact-is-small/#:~:text=Even%20among%20those%20who%20bought,of%20plant%2Dbased%20options%20rose.

right to choose the products that work best for themselves and their families, and the consumer research FDA relies on shows that this is exactly what they are doing. Given that consumers are not confused by the inclusion of the term "milk" on plant-based milk labels, there are no grounds for prohibiting the use of the term. On the contrary, the First Amendment protects the right of plant-based milk producers to use non-misleading labels, such as those that include the term milk along with the plant source.[5] The First Amendment also protects consumers' right to receive non-misleading commercial information about plant-based milk products.[6] In sum, both consumer research and First Amendment jurisprudence support the nomenclature scheme set forth in the draft guidance.

Imitation

In section III.1.7 of the draft guidance, FDA states that, while not all plant-based milks meet the definition of an imitation product under section 403(c) of the FDCA, "to the extent they do" the agency will "exercise enforcement discretion." GFI urges the agency to clarify this statement and specify that plant-based milks that use the naming scheme set forth in the draft guidance are not imitation products under section 403(c) of the FDCA.

A food is only an imitation and thus subject to the requirements of section 403(c) of the FDCA "if it is a substitute for and resembles another food but is nutritionally inferior to that food."[7] Under FDA's regulations, a food that is a substitute for and resembles another food is *not* deemed to be an imitation if: (1) it "is not nutritionally inferior to the food for which it substitutes and which it resembles"; and (2) its label bears a common or usual name or, in the absence of an existing common or usual name, an appropriately descriptive term or fanciful name that is truthful and not misleading.[8] FDA regulations further provide that "nutritional inferiority" includes a "reduction in the content of an essential nutrient that is present in a measurable amount."[9]

The draft guidance makes clear that "[c]ommon or usual names have been established by common usage for some plant-based milk alternatives," including soy milk, almond milk, "and others that qualify the term 'milk' with the plant source of the food." A common or usual name accurately describes the basic nature of a food and explains what the food is "in a way that distinguishes it from different foods."[10] It would be logically inconsistent to consider a food that

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[5] *Central Hudson Gas & Elec. Corp. v. Public Serv. Comm'n of New York*, 447 U.S. 557, 566 (1980); *see Ocheesee Creamery LLC v. Putnam*, 851 F.3d 1228, 1240 (11th Cir. 2017); *Miyoko's Kitchen v. Ross*, No. 20-CV-00893-RS, 2021 WL 4497867, at *4-6 (N.D. Cal. Aug. 10, 2021).
[6] *Va. State Bd. of Pharmacy v. Va. Consumer Council*, 425 U.S. 748, 757 (1976).
[7] 21 C.F.R. § 101.3(e)(1).
[8] *Id.* § 101.3(e)(2).
[9] *Id*. § 101.3(e)(4)(i).
[10] 21 C.F.R. 102.5(a).

is labeled with its common or usual name to be an imitation of a wholly separate food. Making clear that plant-based milks that are named in accordance with FDA's guidance are not imitations of cow's milk will correct this potential inconsistency.

Moreover, the purpose of the imitation provision is to "protect the consumer from [the] uninformed purchase of an inferior substitute product, which could be mistaken for a traditional food product."[11] Appropriately labeled plant-based milks are not imitation foods. First, as FDA recognizes in the draft guidance, common or usual names have been established for some plant-based milks, including "soy milk," "almond milk," and "others that qualify the term 'milk' with the plant source of the food." Where a common or usual name has not been established for a particular plant-based milk product, the label for the food should bear an appropriately descriptive term, and FDA's draft guidance provides input to manufacturers on how to label such products. Accordingly, such appropriately labeled plant-based milk products would not meet FDA's definition of an imitation food under 21 C.F.R. § 101.3(e), and are distinguishable from cow's milk.

Second, as FDA also recognizes, research demonstrates that consumers are not mistaking plant-based milk for cow's milk, nor purchasing plant-based milks by mistake. In sharp contrast, consumers understand the difference between plant-based milk and cow's milk and *choose* to purchase plant-based milk specifically because it is not cow's milk. Thus, plant-based milks are not products that are "mistaken for" cow's milk. Rather, plant-based milks are wholly separate and distinct foods, not inferior substitutes parading as cow's milk products.[12] The draft guidance recognizes as much, stating that plant-based milks "do not purport to be nor are they represented as milk." Furthermore, the formulation of plant-based milks does not constitute a "reduction in the content of an essential nutrient" found in cow's milk. The term "reduction" implies that the imitation food has taken an original recipe and made tweaks that in some way reduce essential nutrients, usually by substituting cheaper ingredients and fillers for more expensive ingredients.[13] For example, spreadable peanut products that are nutritionally inferior to peanut butter are considered imitation peanut butter.[14] Both peanut butter and imitation peanut butter are comprised primarily of ground peanuts, but peanut butter may not contain more than 10% non-peanut ingredients, whereas imitation peanut butter is permitted to contain a higher percentage of filler ingredients,[15] which can result in these products having reduced amounts of the essential nutrients found in peanut butter. Similarly, a product primarily comprised of cow's milk but

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[11] IMITATION FOODS Application of Term "Imitation," 38 Fed. Reg. at 2138 (Jan. 19, 1973).
[12] "[A]lmond milk is not a 'substitute' for dairy milk as contemplated by section 101.3(e)(1) because almond milk does not involve literally substituting inferior ingredients for those in dairy milk." *Painter v. Blue Diamond Growers*, 757 F. App'x 517, 519 (9th Cir. 2018).
[13] Nigel Barella, *The Death of Imitation*, 77 Food & Drug L.J. 359, 367 (2023).
[14] 21 C.F.R. § 102.23.
[15] *See id.*; 21 C.F.R. § 164.150.

diluted with filler ingredients might be considered imitation milk if the resulting product has reduced levels of an essential nutrient found in cow's milk. On the contrary, plant-based milks do not contain *any* cow's milk, or even the same ingredients as cow's milk, and thus cannot be considered a modified or diluted version of cow's milk. "A wholly distinct product formulated from scratch cannot entail a reduction of nutrients from the level present in another food."[16] Thus, plant-based milks cannot be imitations of cow's milk, especially when accurately labeled.

Finally, as written, section III.1.7 of the draft guidance leaves open the possibility of patchwork enforcement of the imitation provision at the state level, as well as opportunistic class action lawsuits. Courts have held that an intent to exercise enforcement discretion generally does not have preemptive effect under the Supremacy Clause.[17] Thus, state regulators could seek to enforce the imitation provision against plant-based milks or private plaintiffs could allege that the labeling of plant-based milks is deceptive under state law, despite those products complying with FDA's naming scheme under the FDCA. This would put plant-based milk producers in the untenable position of having to print separate labels for individual states. Given that most retail distribution agreements are regional or national, rather than state-specific, this would likely be an impossible task. Clarifying section III.1.7 would ensure uniform enforcement and avoid conflicting labeling decisions in different jurisdictions.

Voluntary Nutrient Statements

The voluntary nutrient statement labeling scheme set forth in the draft guidance raises a number of serious concerns. The scheme would have plant-based milks that use the term "milk" in their name include a front-of-pack statement describing how the product differs from cow's milk with respect to nine nutrients: calcium, protein, vitamin A, vitamin D, magnesium, phosphorous, potassium, riboflavin, and vitamin B12. The draft guidance states that the comparison should be "near and visually connected to the name of the product."

GFI acknowledges that the labeling scheme set forth in the draft guidance is not legally binding. However, as regulated entities, food producers generally strive to comply with all applicable guidance from FDA. Moreover, consumer class action lawsuits are common whenever food companies decline to follow the strict letter of agency guidance, even where that guidance is voluntary. Accordingly, GFI urges FDA to consider the real-world impact of this guidance on food producers when determining whether to retain this proposed nutrient statement labeling scheme. We outline several of the drawbacks of implementing the nutrient labeling scheme below.

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[16] Barella, *supra* note 13, at 367.
[17] *Reid v. Johnson & Johnson*, 780 F.3d 952, 964-65 (9th Cir. 2015).

Consumer Confusion

The nutrient labeling scheme has the potential to cause, rather than prevent, consumer confusion. Consumers have been relying on the Nutrition Facts Panel for information on key nutrients for over three decades. The Nutrition Facts Panel is usually placed on the information panel, not on the front of the package. While producers can place nutrient content claims on the front of pack,[18] these claims are often cabined to one or two characteristics of the product and do not generally contain a laundry list of nutrients either contained or not contained in the food. Placing a set of nutrients on the front of pack that differs in part from the list of nutrients on the Nutrition Facts Panel on the back or side of the package could easily confuse shoppers. Furthermore, including statements about nutrients that are not under-consumed, like protein and magnesium, on the front of pack could mistakenly lead consumers to believe they should seek out beverages high in these nutrients in order to maintain a healthy diet. The Dietary Guidelines for Americans (DGA) and Nutrition Facts Panels equip consumers with the information they need to create a balanced diet that meets their needs. Adding a new subset of nutrients to the principal display panel for one category of foods is likely to muddle the information consumers have come to understand about nutrition and diet.[19]

Underinclusiveness & Overbreadth

In addition, FDA's proposed nutrient labeling scheme is not inclusive and does not help people who cannot drink cow's milk due to allergy, intolerance, religious practice, or other reasons. It suggests that consumers should choose cow's milk, but gives them no useful information if they cannot or choose not to do so. If FDA is concerned about the underconsumption of certain nutrients, a better option would be to provide consumer education on *all* of the foods that are good sources of these nutrients, rather than trying to impose a single product on consumers.

At the same time, the nutrient labeling scheme is far more extensive than necessary to serve FDA's stated goals of improving healthy dietary patterns and making information readily available to consumers. The scheme is overbroad because it includes nutrients that are neither under-consumed nor of public health concern for most Americans, relies on inconsistent consumer research, and discounts simpler and less burdensome methods of achieving these same goals.

There is a clear mismatch between nutrients that are of public health concern, or that are otherwise under-consumed by most Americans, and those the FDA proposes to include in

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[18] 21 CFR 101.13(c).

[19] This is especially true in light of FDA's ongoing work on front-of-pack labeling. If FDA develops a front-of-pack labeling scheme for packaged foods in the near future that differs from the front-of-pack labeling scheme proposed in the draft guidance, it could create additional confusion for consumers.

comparative nutrient statements. For example, protein is neither under-consumed nor a nutrient of public health concern. According to the 2020 Dietary Guidelines Advisory Committee "intakes of…total Protein Foods generally meet or exceed recommended amounts for most age-sex groups."[20] Likewise, the Committee found that vitamin A and magnesium do "not appear to pose a public health concern."[21] Phosphorus, riboflavin, and vitamin B12 are also not considered nutrients of public health concern in the DGA. Including all of these nutrients, which are not consumed at levels that pose a public health concern, as part of comparative nutrient statements on the principal display panel creates an excessive burden on plant-based milk producers yet does little to further FDA's goal of ensuring Americans consume healthful diets.

The discrepancy between the nutrients FDA proposes to include in comparative nutrient statements and those that most Americans actually under-consume is not surprising given the source FDA uses as the basis for comparison. The proposed nutrients are borrowed from the USDA Food and Nutrition Service's (FNS) Fluid Milk Substitutes Nutrient Criteria. These criteria were primarily derived from the School Lunch Act and were created for limited populations in limited circumstances—namely for children whose meals are supplied by schools and for mothers, infants, and toddlers in the WIC program. Given this history, there is no reason to assume that these same criteria are appropriate for the general population.

Furthermore, cow's milk is not necessarily the primary source of these nutrients in American diets. For example, most protein in the Healthy U.S.-Style Dietary Pattern is obtained through the protein foods group as well as beans, peas, and lentils.[22] And while the DGA recognizes the dairy food group as a good source of magnesium, phosphorus, potassium, riboflavin, and vitamin B-12, it does not specify *cow's milk* as the primary source of these nutrients. Rather, it includes yogurt, cheese, and fortified soy beverages and yogurt. Importantly, many consumers who choose plant-based milks consume other products within the dairy category, and thus their consumption of plant-based milk does not imply that they will not obtain adequate nutrients from other foods. Recent consumer data indicates that at least 91% of consumers who purchase plant-based milk also purchase animal-based cheese.[23] And while fluid milk provides the majority of dairy intake for children ages 3 and under, "[c]heese surpasses milk as the main source of dairy as people age."[24] Similarly, the draft guidance notes that USDA found milk to be "the primary food source for riboflavin, vitamin B12, magnesium, phosphorus, and potassium *for children*" but not for Americans generally. The draft guidance applies to all plant-based milk products, not

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[20] U.S. Department of Agriculture and U.S. Department of Health and Human Services, *Scientific Report of the 2020 Dietary Guidelines Advisory Committee* [hereinafter DGA Scientific Report], at 25.
[21] *Id.* at 62.
[22] U.S. Department of Agriculture and U.S. Department of Health and Human Services, *Dietary Guidelines for Americans, 2020–2025* [hereinafter DGA], at 128.
[23] National Consumer Panel, All Outlets, 52 weeks ending January 1, 2023.
[24] DGA Scientific Report, *supra* note 20, at 80.

just those targeted at children or offered as part of school lunch programs. FDA should account for this in shaping any final guidance that recommends comparative nutritient statements.

Finally, even looking at the nutrients of public health concern included in Appendix I of the draft guidance, there are many sources of these nutrients beyond cow's milk. According to USDA, there are over 100 food sources for potassium, over 30 for calcium, and almost 20 for vitamin D.[25] Many fruits and vegetables contain more potassium per serving than cow's milk, and several protein foods provide more vitamin D.[26] Even calcium can be found in equal or greater amounts in some fruits, vegetables, protein foods, and other dairy products, compared with cow's milk.[27] FDA's final guidance should take into account the range of foods Americans can consume to obtain adequate levels of these key nutrients and consider entire diets, rather than single foods. The agency should also ensure that any guidance on comparative nutrient statements actually accomplishes its goal of ensuring Americans eat nutritious diets, rather than pushing a single product that many consumers cannot or will not consume.

Unfair and Unlevel Playing Field

FDA's proposed nutrient labeling scheme unfairly discriminates against plant-based milk products in the marketplace. Consumers are often unfamiliar with the nutritional complexities of the foods they consume.[28] Just because the average consumer cannot list every micronutrient found in cow's milk or plant-based milk does not justify singling out plant-based milk for special treatment. Other milk products, like chocolate milk or unfortified skim milk, do not have to display comparative nutrient statements. Meanwhile, all plant-based milks, including flavored milks that are not intended to be used in the same way as plain cow's milk, are treated differently. And other foods that have similar functions but different nutritional profiles compared to historically-consumed foods (e.g., gluten-free bread) are not subject to this type of comparative labeling scheme. If the nutrients set forth in Appendix 1 of the draft guidance are so essential to human health that consumers should be aware of their content in foods, FDA should require them to be included on the Nutrition Facts Panel for all foods, not specifically called out

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[25] U.S. Department of Agriculture, *Current Dietary Guidelines Food Sources of Select Nutrients,* https://www.dietaryguidelines.gov/resources/2020-2025-dietary-guidelines-online-materials/food-sources-select-nutrients#:~:text=Calcium%2C%20potassium%2C%20dietary%20fiber%2C,for%20the%20general%20U.S.%20population (last visited Apr 17, 2023).

[26] *See id.*

[27] *See id.*

[28] *See, e.g.*, Parke Wilde et al., *Consumer confusion about wholegrain content and healthfulness in product labels: a discrete choice experiment and comprehension assessment*, 23 Pub. Health Nutrition 3324–3331 (2020); *Think You Know? Think Again: Americans Don't Understand Much About Nutrition*, PR Newswire (Nov, 2, 2022), available at https://www.prnewswire.com/news-releases/think-you-know-think-again-americans-dont-understand-much-about-nutrition-301665046.html.

on one type of product in the marketplace. That way, consumers can determine for themselves how best to create a nutritious diet while accommodating allergies, intolerances, religious practices, and ethical concerns.

Furthermore, by recommending comparative nutrient statements only on plant-based milks, the draft guidance fails to grapple with the benefits that plant-based milks can offer that cow's milk generally does not, like fiber (a dietary component of public health concern under the DGA), vitamin E, and higher amounts of iron, as well as no cholesterol and little to no saturated fat.[29] If FDA recommends that plant-based milks call out nutritional differences from cow's milk, then a similar recommendation should apply to cow's milk. The DGA promotes reducing saturated fat and dietary cholesterol intake.[30] The Scientific Report of the 2020 Dietary Guidelines Advisory Committee also found that the majority of Americans in all age and sex groups exceed the recommended energy intake from saturated fat.[31] The DGA also identifies fiber as a nutrient of public health concern and notes that over "90 percent of women and 97 percent of men do not meet recommended intakes for dietary fiber."[32] Based on the logic applied to plant-based milk products in the draft guidance, cow's milk products should state that they are higher in cholesterol and saturated fat compared to plant-based milk and that they do not contain fiber.

Inconsistent and Inconclusive Consumer Research

The proposed nutrient labeling scheme is predicated on inconsistent consumer research that does not fully support FDA's conclusions and does not account for research indicating that consumers *do* understand nutritional differences between plant-based milk and cow's milk. Without public access to several of the studies FDA relied on, GFI cannot assess the methodology and potential bias of all of the consumer research used, but FDA concedes that some of the studies it relies on may be biased or have limited reliability, validity, and usefulness.[33]

From the information publicly available, it appears that several of the consumer studies show inconsistent results and do not fully support FDA's conclusion that consumers believe plant-based milks are nutritionally equivalent to cow's milk. For example, one study found the

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[29] *See, e.g.*, Silk Original Almond Milk Nutrition Facts, available at https://silk.com/plant-based-products/almondmilk/original-almondmilk/; Blue Diamond Original Almond Milk Nutrition Facts, available at https://www.bluediamond.com/brand/almond-breeze/almondmilk/original#features; Planet Oat Original Oat Milk Nutrition Facts, available at https://planetoat.com/products/original-oatmilk/; Pacific Foods Oat Plant-Based Beverage, Original, Nutrition Facts & Ingredients, available at https://www.pacificfoods.com/products/pacific-foods/organic-oat-original-beverage/.
[30] DGA, *supra* note 22, at 44.
[31] DGA Scientific Report, *supra* note 20, at 71.
[32] *Id.* at 34, 101.
[33] U.S. Food and Drug Administration, *Memo: Summary of consumer research reports on consumers' perceptions and understanding of plant-based milk alternatives* (Feb. 3, 2023) at 1.

majority of respondents do not think almond milk had the same nutrients as cow's milk: "When compared to plain dairy milk, respondents, and particularly regular dairy milk buyers, appear to think plain almond milk is less likely to be a good source of calcium, to help build and maintain strong bones and teeth, or to contain vitamin D" and "65% say that plain dairy milk is a good source of calcium vs. 33% plain almond milk; 60% plain dairy milk helps build and maintain strong bones and teeth vs. 27% plain almond milk; and 59% plain dairy milk contains vitamin D vs. 22% plain almond milk."[34] The study also found almond milk drinkers "compare plain dairy milk favorably to plain almond milk as being a good source of calcium, in helping build and maintain bones and teeth, and in containing vitamin D." *Id.* These results show that consumers of both cow's milk and almond milk do not believe plant-based milks are nutritionally equivalent to cow's milk. Another study found that most consumers did not know how different nutrients compared between plant-based milks and cow's milk or thought it would depend on the plant source.[35] Yet another study found that respondents believe cow's milk is a better source of vitamins, minerals, and protein than plant-based milks.[36] And another found consumers perceive cow's milk as having more protein and fat, but less sugar, depending on the plant-based product.[37] None of these findings support the conclusion that consumers think the two products are nutritionally *equivalent*; on the contrary, they demonstrate that consumers do, in fact, understand that there are nutritional differences between cow's milk and plant-based milks as well as among different plant-based milks.

One study not considered by FDA actually found that "participants were more knowledgeable about differences between plant-based and animal-based products than they were about differences among animal-based products (i.e., whole milk v. skim milk)."[38] When asked to compare almond milk and whole cow's milk, 85 percent of respondents accurately identified which product had more fat, 71 percent accurately identified calories, 70 percent accurately identified cholesterol, 67 percent accurately identified fiber, and 48 percent accurately identified sugars.[39] Respondents had more difficulty identifying these differences when comparing whole and skim milk.[40]

The consumer studies FDA relied upon are also inconsistent in how they frame "nutrients" and none of them include the entire list of nutrients that FDA is evaluating for inclusion in the proposed comparative nutrient statements. A study conducted by the National Dairy Council,

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[34] *Id.* at 12.
[35] *Id.* at 9.
[36] *Id.* at 4.
[37] *Id.*
[38] Silke Feltz & Adam Feltz, *Consumer accuracy at identifying plant-based and animal-based milk items*, 4 Food Ethics 85–112 (2019) (attached as Exhibit 1).
[39] *Id.*
[40] *Id.*

which questioned more cow's milk buyers than plant-based milk buyers, asked the respondents about differences in "key nutrients" which they defined as "(e.g., calcium, potassium, etc.)."[41] A study by Consumer Reports defined key nutrients instead as "protein, calcium, vitamin A and potassium."[42] And a third, funded by Dairy Management Inc., included "natural sugars and fiber content."[43] It is difficult to understand how FDA concluded that the consensus among such different studies was that consumers believe cow's milk and plant-based milks to be nutritionally equivalent across nine different nutrients, especially when several of the studies showed respondents had strong opinions on the *differences* between cow's milk and plant-based milks.

The consumer studies also highlight an important aspect that the draft guidance overlooks: many consumers choose plant-based products *because* of their nutritional differences from cow's milk. Plant-based milk is healthier than cow's milk in some aspects, including with respect to levels of saturated fat, cholesterol, fiber, and total sugar, and many consumers are specifically seeking out those benefits.[44] FDA's own focus group found that consumers see plant-based milks "as healthier than milk because they are lower in fat and cholesterol and do not contain animal ingredients."[45] The focus group also found that "[p]articipants who knew that plant-based milk alternatives can be lower than milk in protein and calcium did not consider this an issue due to other benefits of plant-based milk alternatives." The proposed nutrient labeling scheme discounts the benefits that purchasers of plant-based milks want, and would discourage their efforts to seek options that are lower in cholesterol and saturated fat, in contravention of the DGA.

Contradicting Climate Goals

Finally, the nutrient labeling scheme may discourage the consumption of plant-based milks despite their environmental and climate benefits, which in turn benefit public health. Plant-based milk production emits significantly fewer GHGs, contributes less to eutrophication, and uses less water and land than the production of cow's milk.[46] Deterring consumption of products with such a direct benefit to the climate contradicts America's global climate commitments and the

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41 National Dairy Council, Consumer Perceptions: Dairy Milk and Plant-based Milk Alternatives (October 29, 2018).
42 Consumer Reports, Plant-Based Milk Survey (October 31, 2018) at 4.
43 U.S. Food and Drug Administration, *Memo: Summary of consumer research reports on consumers' perceptions and understanding of plant-based milk alternatives* (Feb. 3, 2023) at 12.
44 Notably, the Dietary Guidelines Advisory Committee found "[r]educed risk of all-cause mortality was observed in several studies that examined dietary patterns without animal-products, such as those described as vegetarian, vegan, or determined by 'plant-based' diet indices." DGA Scientific Report, *supra* note 20, at 34.
45 *Id.* at 13.
46 Hannah Ritchie, *Dairy vs. plant-based milk: What are the environmental impacts?* Our World in Data (2022), available at https://ourworldindata.org/environmental-impact-milks.

Biden Administration's whole-of-government approach to climate change.[47] It also discounts the significant relationship between environmental degradation, climate change, and human health. For example, cow's milk has been shown to have an 84 percent greater damaging impact on human health via its impact on climate change compared to soy milk.[48]

Potential Solutions

For all of these reasons, GFI urges FDA to remove the comparative nutrient statement labeling scheme in its final guidance. In the alternative, we ask FDA to reconsider the nutrients to be included in the voluntary nutrient statements and focus instead on under-consumed nutrients or nutrients of public health concern that most Americans get primarily from cow's milk and are not getting in sufficient amounts elsewhere in their diet. To minimize consumer confusion, we also encourage the agency to allow any such voluntary nutrient statements to appear on the information panel along with the Nutrition Facts Panel, rather than on the principal display panel.

Conclusion

The draft guidance recognizes that consumers are not confused by plant-based milk labels that include the term "milk" and logically concludes that the term is permissible on these labels so long as it is qualified with information about the plant source(s) used.

Despite this conclusion, and despite acknowledging that plant-based milks are separate products that do not hold themselves out as cow's milk, the draft guidance recommends a burdensome comparative nutrient labeling scheme that is more likely to cause consumer confusion than alleviate it. As written, the guidance puts an expensive and unfair burden on plant-based milk companies, in addition to exposing them to consumer litigation, and is not tailored to achieve the agency's goals of promoting healthful diets and providing consumers access to information. The draft guidance also leaves the important issue of imitation labeling ambiguous and open to patchwork state enforcement. GFI urges FDA to reconsider the comparative nutrient statement scheme proposed in the draft guidance and clarify that plant-based milks labeled with their plant source and the term milk are not imitation products.

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[47] The White House, *President Biden takes executive actions to tackle the climate crisis at home and abroad, create jobs, and restore scientific integrity across Federal Government* (2021), https://www.whitehouse.gov/briefing-room/statements-releases/2021/01/27/fact-sheet-president-biden-takes-executive-actions-to-tackle-the-climate-crisis-at-home-and-abroad-create-jobs-and-restore-scientific-integrity-across-federal-government/.

[48] Denise Filippin et al., *Environmental Impact of Two Plant-based, Isocaloric and Isoproteic Diets: The Vegan Diet vs. the Mediterranean Diet*, 20 Int'l J. of Envtl. Res. & Pub. Health, 3797 (2023) (attached as Exhibit II).

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Exhibit 1

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SHORT POLICY BRIEF

Consumer Accuracy at Identifying Plant-based and Animal-based Milk Items

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Abstract
Are people are product literate enough to make informed decisions about plant-based and animal-based milk products? In 8 studies, we provide evidence that consumers do not make mistakes indicative of pervasive lack of milk product literacy. People were accurate at identifying plant-based and animal-based milk and cheese products as being plant or animal-based (74% - 84% of the time). In a more difficult task, participants were generally accurate at identifying nutritional differences between plant-based and animal-based milk and cheese products (50%–62% accuracy). We also developed the Milk Literacy Scale, which is a 12-item, validated, knowledge-based instrument that measures knowledge of differences among plant-based and animal-based milk products. The Milk Literacy Scale predicted accuracy in both identification tasks. All results were replicated in a large sample ($N = 1054$). These results suggest that people are generally product literate about milk products to make informed choices. The studies offer some insights into what kinds of interventions would help make people even more product literate.

Keywords Product literacy · Numeracy · Plant-based · Animal-based; Milk; Item response theory

Introduction

On June 14, 2017, the European Parliament ruled that producers of plant-based milk products could no longer use the terms 'cheese' or 'milk' to describe their products. Those terms (along with the related terms like 'whey', 'cream', 'butter', 'buttermilk', and 'yogurt') are to be exclusively used for items that contain animal milk. Among the major reasons for this decision is the risk of confusion for consumers if terms traditionally used to designate animal-based

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milk items (e.g., milk, cheese) were also used for plant-based milk items (e.g., soy milk, soy cheese). Similar pieces of legislation are being considered in other parts of the world but have not yet been adopted (e.g., the Dairy Pride Act in the United States; the Nationals' platform in Australia). But do people make mistakes when identifying plant-based and dairy-based food items? Are people product literate enough to reliably distinguish plant-based milk products from dairy-based milk products?

We present 8 studies to help address these questions. Studies 1–3 present a short, objective 12-item measure of plant-based milk and animal-based milk knowledge. Studies 4 and 5 provide evidence that people are generally accurate at identifying plant-based and animal-based milk products as plant or animal-based, and this accuracy is predicted by knowledge of milk products and general nutrition knowledge. Studies 6 and 7 suggest that people are also able to accurately identify nutritional differences between plant-based and animal-based milk products. Again, accuracy was predicted by increased knowledge of milk products and general nutrition knowledge. Study 8 replicated the results from Studies 1–7 on a large sample. Study 8 also allowed testing path models indicating that while knowledge of milk products and general nutrition knowledge were prominent predictors of accuracy, numeracy was also related to increased identification accuracy. These results suggest that generally people are product literate enough to identify key differences between plant-based and animal-based milk products. The results also illuminate avenues for helping those who are not product literate enough to make those distinctions.

Theory: Consumer Product Literacy

Nearly all plant-based milk items are labeled as such (e.g., soy milk, vegan cheese). On the face of it, then, a conscientious consumer should have no trouble distinguishing plant-based and dairy-based milk items simply by reading the label. However, whether consumers use information on product labels is context sensitive and depends on individual motivations and backgrounds (for reviews, see Hall and Osses (2013), and Hess et al. (2012)). By some estimates, nearly everyone uses some information on product labels especially if the labels have the following features: graphs or symbols, adjective labels with minimal numerical information, and information on the front of the package (Campos et al. 2011).[1] Consequently, nutrition labels can contain "highly credible sources information, and many consumers report using nutrition labels to guide their selection of food products" (Campos et al. 2011, pp. 6–7).

One of the justifications for restricting the use of milk terms is that using terms like 'cheese' and 'milk' for plant-based products leads to consumer confusion. Even if people use labels in making decisions, those people will not generally be able to make accurate decisions about the milk products they buy. There are many examples of people not understanding information on product labels. For instance, while people generally understand the term 'calorie' they have difficulty linking calories to other concepts like energy and have trouble converting numerical information about calories meaningfully (Cowburn and Stockley 2005). In this light, one could argue that using 'milk' terms in an environment that includes plant-based products would lead to misunderstandings like those seen with the term 'calorie.' People might in principle understand the difference between plant-based and animal-based milk products, but they

[1] This same systematic review suggested that nearly 75% of Americans report using nutrition labels at least sometimes when they make a buying decision.

would not be able to meaningfully translate that understanding into an accurate buying decision.

The central issue is whether people are product literate enough about milk items to be informed consumers. Product literacy can be defined as “the degree to which consumers have the capacity to locate, evaluate, apply, and communicate basic information needed to make appropriate product related decisions” (Kopp 2012, p. 196). For some products and applications, people do not have adequate product literacy (e.g., with calories). However, in other instances, people are very product literate. For example, people tend to be able to make simple comparisons and understand some vocabulary that is presented on labels (Cowburn and Stockley 2005).

There are at least two different current arguments that have been offered for thinking that people generally are not product literate enough about milk products. The first argument is that people might be confused about which products are animal-based and which products are plant-based. For example, according to the European Court’s ruling, “In the absence of such limits, those designations would not enable products with particular characteristics related to the natural composition of animal milk to be identified with certainty” (Case C-422/16, §44). Mistaking the nature of a product is the most basic kind of mistake that consumers could make. It stands to reason that if a person cannot accurately identify what a product is, then that person will also not be able to reliably identify other relevant properties of that product (e.g., nutritional content and differences with other products, environmental impacts).

A different argument holds that even if people are product literate enough to identify plant-based and animal-based products as such, they are not product literate enough to understand nutritional differences between plant-based and animal-based products. For example, according to the Dairy Pride Act (2017), there is the risk that consumers would mistakenly assume nutritional equivalency between plant-based and animal-based ‘milk’ products. As the argument goes, the proper protection given such mistakes is to create or enforce legislation that bans using ‘milk’ terms for anything other than animal-based products.

To our knowledge, all of these claims about milk product literacy are not empirically tested. We set out to test them in 8 studies. The studies proceeded in three stages. The first stage was aimed to develop a research instrument to measure *Milk Literacy*. The Milk Literacy Scale (MLS) was designed to be an objective, general knowledge based instrument measuring what people know about differences between (a) animal-based and plant-based milk products and (b) different animal-based milk products (Studies 1–3). The second stage was designed to test whether people could accurately identify milk and cheese products as being animal or plant-based (Studies 4 and 5). The third stage was designed to test the degree to which people can accurately identify nutritional differences between animal-based and plant-based milk items (Studies 6 and 7). Study 8 was designed to replicate findings of Studies 1–7 in a larger sample and model responses.

Milk Literacy Scale

The first step in our planned series of studies was to develop an objective test of knowledge of plant-based and animal-based milk products. Having an objective measure of knowledge of plant based and animal based milk products is important for at least three reasons. First, we can determine how much people know about plant based an animal based milk products. Second, and more importantly, we can use knowledge of plant based and animal based products as a predictor of other judgments like milk product identification (Studies 4–5) and milk product nutrition identification (Studies 6–7). Third, in some instances it is relatively easy to make people more knowledgeable with educational interventions. Having a validated measure of knowledge affords the ability to measure if educational interventions make people more knowledgeable.

We used Item Response Theory (IRT) to develop the MLS. IRT analyses measure latent traits. Latent traits are unobserved yet assumed to be causally responsible for a pattern of responses (Baker 2001). In this case, the latent trait is knowledge of milk products. Unlike classical test theory, IRT can provide item-level analyses. In particular, IRT methods can estimate the probability that people of different levels of knowledge will answer a question correctly. If one plots the probabilities of correct answers among people with different levels of knowledge, the resulting plot forms an *S* curve (from low probability of correct answer for low-knowledge people to high probability of correct answer for high-knowledge people). This *S* curve is called the *item characteristic curve*. Difficulty and discrimination are two important properties of item characteristic curves. An item's characteristic curve can be located on a scale of how difficult the item is. Items that have better discrimination will have sharper up-slopes on the *S* curve (i.e., the item does a better job discriminating among low and high ability at that ability location). Ideally for our purposes, the knowledge test should have items with strong discrimination and a variety of difficulties so that different ability levels can be estimated by the test.

Study 1

Study 1 was designed to test an initial battery of items to measure objective knowledge about milk products. The goal of Study 1 was to identify items with desired item-level properties (i.e., discrimination and difficulty). Items with desirable properties were planned to be retained for validation in subsequent studies.

Participants

Two hundred and twenty-eight participants were recruited from Amazon's Mechanical Turk. Amazon's Mechanical Turk data are generally taken to have acceptable quality for these kinds of tasks, especially in comparison to typical subject pools (e.g., university undergraduate subjects pools) (Buhrmester et al. 2011, 2018a, b; Crump et al. 2013; Mason and Suri 2012; Paollacci et al. 2010; Rouse 2015).

Demographics for the participants (for all studies) are reported in Table 1. Also, in all of the studies participants were required to have a United States IP address to participate. Restrictions were implemented so that participants in the Mechanical Turk samples could not participate in more than one study. The Qualtrics sample (Study 8) was completely independent of the Mechanical Turk Sample. All studies were conducted between May 15th, 2019 and September 30th, 2019.

Materials

We developed 23 items that had face validity concerning aspects of soy milk and whole milk (see Appendix 1). Twelve items dealt specifically with nutritional differences between whole cow milk and soy milk (e.g., whole cow milk has more cholesterol than fortified soy milk).

Table 1 Demographics for Studies 1, 3–8

Study #		1	3	4	5	6	7	8
Age	*M*	36.18	38.41	35.7	37.04	35.54	35.76	45.64
	SD	11.02	12.61	12.4	12.53	11.22	11.49	17.85
Male		51.3%	51%	48.8%	57.6%	58.4%	46.3%	34.7%
Religion	Catholic	17.5%	20.3%	21.6%	17.6%	30.4%	27.6%	–
	Protestant	30.7%	31.9%	25.6%	28%	27.2%	26.9%	–
	Mormon	0.9%	0.9%	0.8%	2.4%	1.6%	1.5%	–
	Muslim	2.6%	0.4%	2.4%	2.4%	1.6%	1.5%	–
	Jewish	1.3%	1.3%	5.6%	1.6%	1.6%	1.5%	–
	Atheist	19.3%	18.1%	17.6%	20.8%	12%	19.4%	–
	Agnostic	19.3%	21.1%	16.8%	18.4%	15.2%	17.2%	–
	Preferred not to indicate	8.3%	6%	9.6%	8.8%	10.4%	4.5%	–
Education	Grammar school	0%	0%	0%	0.8%	0.8%	0%	3.3%
	High School	10.5%	9.1%	13.6%	3.2%	10.4%	7.5%	25.8%
	Vocational	5.3%	3.9%	2.4%	3.2%	4%	3.7%	11.1%
	Some College	25%	31.5%	19.2%	27.2%	19.2%	32.1%	23.3%
	Bachelor's	38.6%	40.9%	50.4%	47.2%	45.6%	32.1%	23.6%
	Master's	17.5%	11.2%	8.8%	12%	14.4%	17.2%	–
	PhD	0.9%	0.9%	3.2%	3.2%	0.8%	3.7%	2.1%
	Professional	2.2%	2.6%	2.4%	0%	4.8%	3.7%	10.7%
Ethnicity	Arab	0%	0%	0%	0%	0%	0.7%	–
	Asian/Pacific Islander	5.7%	4.7%	10.4%	7.2%	7.2%	9.7%	9.1%
	Black	8.3%	6%	4.8%	9.6%	5.6%	8.2%	17.3%
	Caucasian/White	76.3%	78%	72.8%	73.6%	77.6%	74.6%	65%
	Hispanic	5.3%	6%	3.2%	6.4%	5.6%	3.7%	–
	Indigenous	0%	0%	0.8%	0%	0.8%	0.7%	1.5%
	Latino	0.9%	0.4%	3.2%	0%	0%	0.7%	–
	Multiracial	2.6%	3.9%	4.8%	0.8%	2.4%	0.7%	–
	Would rather not say	0.9%	0.9%	0%	2.4%	0.8%	0.7%	7.1%
Marital Status	Divorced	5.7%	9.5%	8%	5.6%	5.6%	7.5%	–
	Cohabitation	14.5%	10.8%	12.8%	9.6%	15.2%	4.5%	–
	Married	43.9%	39.2%	38.4%	49.6%	38.4%	44%	–
	Separated	1.8%	1.3%	0.8%	32.8%	0.8%	0.7%	–
	Single	34.2%	36.2%	37.6%	0.8%	36.8%	40.3%	–
	Widowed	0%	1.3%	1.6%	0.8%	3.2%	3%	–
	preferred not to respond	0%	1.7%	0.8%	1.6%	0%	0%	–
Income	<$10,000	3.1%	6.5%	8%	5.6%	4.8%	3%	–
	$10,000-19,999	7%	9.5%	9.6%	3.2%	6.4%	8.2%	–
	$20,000-29,999	16.2%	11.2%	9.6%	13.6%	14.4%	12.7%	–
	$30,000-39,999	14%	11.6%	11.2%	7.2%	14.4%	11.2%	–
	$40,000-49,999	12.7%	12.1%	11.2%	15.2%	7.2%	12.7%	–
	$50,000-74,999	24.1%	22.8%	22.4%	29.6%	24%	16.4%	–
	$60,000-99,999	12.7%	13.4%	14.4%	12%	19.2%	15.7%	–
	$100,000-150,000	5.7%	7.3%	5.6%	9.6%	3.2%	11.2%	–
	> $150,000	3.5%	1.7%	6.4%	3.2%	5.6%	7.5%	–
	Preferred not to respond	0.9%	3.9%	1.6%	0.8%	0.8%	1.5%	–
Living area	Urban	33.8%	30.6%	36%	0.8%	36%	37.3%	–
	Suburban	46.9%	52.2%	47.2%	33.6%	48%	47%	–
	Rural	19.3%	17.2%	16%	45.6%	16%	15.7%	–
	Preferred not to respond	0%	0%	0.8%	20%	0%	0%	–

These nutritional differences were based on an analysis by Vanga and Raghavan (2018). Call this the *Soy* subscale of the MLS. Ten items dealt specifically with differences between whole cow milk and skim cow milk (e.g., whole cow milk has more protein than skim cow milk). Call this the *Milk* subscale of the MLS. We also included one general question concerning whether soy milk is made with some cow milk (Item 23). Participants were asked to rate the statements as either being true or false. Finally, we collected basic demographic information.

Results and Discussion

Analyses proceeded on the assumption that each of the Soy and Milk subscales of the MLS measured only one latent variable (see subsequent studies for evidence for this assumption). Seperate IRT analyses were conducted on each set of items (item 23 was included in the Milk subscale). All IRT analyses were conducted using R (R Core Team 2018) with the LTM package (Rizopoulos 2006). A 2-parameter model was used for each set of items.[2]

As expected, some items did not have desirable properties. Two Milk subscale items (Items 15 and 16) had reverse discrimination (i.e., as one knows more, one is less likely to answer the item correctly). Four items of the Soy subscale items (2, 6, 8, 12) had reverse discrimination, and one item (Item 1) was exceedingly easy and had little discrimination (see Appendix 1 for discrimination and difficulty statistics for each item). Consequently, Item 1 did not offer much information about the latent variable that was being measured.

Study 2

The results of Study 1 suggested several advantageous modifications to the MLS. First, items with reverse discrimination were eliminated for Study 2. Item 1 was also eliminated from subsequent studies. We also randomly selected items to change their true-values (i.e., taking the opposite truth-value) to ensure that the items behaved roughly the same with different truth-values. Theoretically, changing an item's truth value should not change the item's statistical properties if the item is a good, stable indicator of the underlying construct. Finally, the discrimination was relatively low for many of the items. While we did not have direct evidence for this, we suspected that many people guessed at answers they did not know. This would likely result in getting some answers correct by chance and thereby reducing discrimination. To help alleviate this problem, we included an "I don't know" option in this and subsequent studies. Given these modifications, the primary goal of Study 2 was to verify the item-level properties found in Study 1.

Participants

Two hundred and twenty-six participants were recruited from Amazon's Mechanical Turk.[3]

Materials

Participants received the modified MLS (see Appendix 2). Correct answers were coded as '1' and incorrect or 'I don't know' answers were coded as '0'.

[2] A two-parameter model is different from a 1-parameter model. One-parameter models only estimate item difficulty and assume that the discrimination for each item is the same. Three-parameter models include a pseudo-guessing parameter in addition to estimating difficulty and discrimination that helps to control for people getting items correct simply by guessing (Baker, 2004).
[3] A coding mistake prevented demographic data from being collected in Study 2.

Results and Discussion

Two separate IRT analyses using 2-parameter models were conducted, one for the Milk subscale and one for the Soy subscale of the MLS. The items of the modified scale largely had acceptable discrimination along with a range of difficulties (see Table 2).

However, the results of Study 2 suggested that further refinements of the MLS were possible. First, two items in the Soy subscale had very low discrimination (Items 1 and 4, .23 and .29 respectively). Four items in the Milk subscale had similar difficulty (Items 10, 11, 13, and 15; 0.5, 0.61, 0.53, and 0.54 respectively). So, some of those four items could be eliminated without loss of information from the scale (i.e., they all identified people at the same ability level, so those items were redundant).

Study 3

Study 3 was designed to replicate the IRT results of Study 2 with the modifications suggested by Study 2. Study 3 was also designed to demonstrate that the MLS was multidimensional consisting of two unidimensional subscales (i.e., Soy and Milk subscales). Finally, there was good reason to think that the 12-item Milk Literacy scale was going to have acceptable formally IRT properties. Study 3 afforded the opportunity to begin to demonstrate convergent and divergent validity of the MLS. To help establish convergent validity, we included the Nutrition Knowledge Scale (Dickson-Spillmann et al. 2011). If the MLS measures food knowledge, then the MLS score should be related to general nutrition knowledge. To help establish divergent validity, participants responded to a general personality inventory. If the MLS measures knowledge, then it should be largely unrelated to general personality traits.

Participants

Two-hundred and thirty participants were recruited from Amazon's Mechanical Turk.

Table 2 Descriptive IRT Statistics for the MLS in Studies 2, 3, and 8

Item	% correct			Difficulty			Discrimination		
Study #	2	3	8	2	3	8	2	3	8
Knowledge 1	25			4.89			0.23		
Knowledge 2	77	73	73	−1.01	−.81	−1.12	1.7	1.95	1.06
Knowledge 3	80	80	79	−0.96	−1.02	−1.12	3.0	2.43	1.75
Knowledge 4	36			1.95			0.29		
Knowledge 5	65	71	52	−0.74	−0.93	−0.08	1	1.22	1.36
Knowledge 6	52	52	52	−0.09	−0.08	−0.13	1.19	1.06	0.82
Knowledge 7	40	48	41	0.57	0.07	0.42	0.85	1.91	1.01
Knowledge 8	70	77	65	−1.02	−1.22	−0.71	0.95	1.26	1.09
Knowledge 9	27	26	26	1	0.81	0.83	1.28	2.14	2.17
Knowledge 10	35	31	26	0.5	0.58	0.8	2.28	2.79	2.49
Knowledge 11	34			0.61			1.65		
Knowledge 12	26	27	25	1.2	1.42	1.31	1.06	0.81	1
Knowledge 13	37			0.53			1.48		
Knowledge 14	12	11	16	2.64	2.75	2.03	0.86	0.85	0.94
Knowledge 15	32	29	25	0.54	0.69	0.88	4.39	2.39	2.84
Knowledge 16	65	71	51	−1.08	−2.51	−0.1	0.62	0.37	0.44

Materials

The Milk Literacy Scale (MLS). A modified, 12-item version of the MLS was used. In particular, Items 1 and 4 were eliminated from the Soy subscale because they had very low discrimination. Because 4 items in the Milk subscale had similar properties, some of those items could be eliminated without much loss of information. To that end, we eliminated Items 11 and 13 because they had the lowest discrimination of the 4 items. The Soy and Milk subscales of the MLS had 6-items each. Each statement was rated as being either true, false, or the participants could respond that they did not know. Correct answers were coded as '1' and incorrect or "I don't know" responses were coded as '0'. A total correct answer score for each of the two subscales was calculated.

The Nutrition Knowledge Scale (Dickson-Spillmann et al. 2011). The Nutrition Knowledge scale is a 20-item scale with general statements about nutrition (e.g., "Brown sugar is much healthier than white sugar"). Response options were true, false, or "I don't know." Correct answers were coded as '1' and incorrect or "I don't know" responses were coded as '0'. A total correct answer score was calculated for the Nutrition Knowledge Scale.

The Ten-Item Personality Inventory (TIPI) (Gosling et al. 2003). The TIPI is a 10-item measure of the Big Five Personality traits. Each of the Big Five traits is measured by rating how much pairs of adjectives describe one's self (e.g., "extraverted, enthusiastic") on a 7-point Likert scale (Disagree strongly to Agree strongly). Scores for each of the Big Five are calculated by averaging ratings from two pairs of adjectives.

Results and Discussion

A test of unidimensionality was conducted on the entire 12-item MLS. The unidimensionality test determines whether the eigenvalue for a second factor is greater than would be theoretically expected. If the second eigenvalue is greater than would be expected, then one can reject unidimensionality. The theoretical eigenvalue based on 200 Monte Carlo samples was 1. The observed eigenvalue of the second factor in the data was 2.4, significantly greater than the theoretically derived eigenvalue ($p = .005$). Unidimensionality could be rejected for the full MLS. Unidimensionality tests were done for each of the Milk and Soy subscales using the same method. In each case, unidimensionality could not be rejected: Soy subscale observed second eigenvalue = .38, average eigenvalue of 200 Monte Carlo samples = .52, $p = .89$; Milk subscale observed second eigenvalue = 0.82, average of second eigenvalue in 200 Monte Carlo samples = .78, $p = .31$.

A series of IRT analyses were conducted on each subscale of the MLS. The first set of analyses concerned the Soy subscale of the MLS. Planned analyses compared a constrained 1-parameter model to an unconstrained 1-parameter model. The unconstrained 1-parameter ($AIC = 1543.26$, $BIC = 1567.39$) model was a better fit to the data than the constrained model ($AIC = 1559.08$, $BIC = 1579.76$), $p < .001$. The unconstrained 1-parameter model had good fit to the data, passing a goodness of fit test, $p = .17$ and having acceptable residuals on the margins (all chi squared values <1.31). A 2-parameter model ($AIC = 1544.33$, BIC 1585.69) was not significantly better than the 1-parameter unconstrained model, $p = .11$. However, the 2-parameter model also had acceptable fit to the data with all chi square values of residuals on the margins less than .76.

We performed the same series of IRT analysis on the Milk subscale of the MLS. A 1-parameter unconstrained model ($AIC = 1463.17$, $BIC = 1487.3$) was a better fit to the data than a 1-parameter constrained model ($AIC = 1466.87$, $BIC = 1487.55$), $p = .02$. A 2-parameter ($AIC = 1434.11$, BIC 1475.47) model was a better fit to the data than a 1-parameter unconstrained model, $p < .001$. The 2-parameter model also had acceptable residuals on the margins for the items, all chi squared values <1.24.

The IRT analysis suggested that the 12-item version of the MLS had acceptable internal properties. Convergent, divergent, and criterion validity remained to be demonstrated. While we planned to establish criterion validity in subsequent studies, some evidence for convergent and divergent validity could be provided in the current study. Correlations were calculated between the variables gathered (see Table 3).

As expected, both of the MLS subscales were moderately to strongly related to the Nutrition Knowledge Scale, suggesting convergent validity. The Soy subscale of the MLS was also moderately related to the global personality trait conscientiousness. This somewhat unexpected finding makes sense in the context that conscientious people are likely to be more engaged and vigilant about what they eat (Lunn et al. 2014). The Soy and Milk subscales were weakly related to other personality traits suggesting divergent validity.

Of note, the Milk subscale of the MLS ($M = 1.95$, $SD = 1.5$) was more difficult than the Soy subscale ($M = 4$, $SD = 1.7$), $t(231) = 15.7$, p, .001, $d = 1.03$. This result suggests that people are less knowledgeable about the differences among animal-based 'milk' products then they are about differences between animal-based and plant-based milk products, at least as measured by the MLS. Some interpretive caution should be taken, however. Items were selected for each scale in part because of the difficulty of the items. So, we may have selected items for the Milk subscale that were slightly more difficult than the items for the Soy subscale. These more difficulty items would result in an overall lower total score on the Milk subscale.

Production Identification

One of the main arguments for forbidding the use of 'milk' terms for plant-based products is that the usage would cause confusion among consumers. Studies 4 and 5 were designed to determine how good people are at correctly identifying animal based and plant-based milk products as plant or animal-based. Two types of milk products were selected because of their general ubiquity and availability. The first set of items (Study 4) was milk items (e.g., soy milk

Table 3 Correlations among dependent variables in Study 3

	1	2	3	4	5	6	7	8	9	10
1. Soy	1									
2. Milk	.23**	1								
3. Nutrition	.52**	.3**	1							
4. Extraversion	−.09	.04	−.03	1						
5. Agreeableness	.13*	.05	.16*	.19**	1					
6. Conscientiousness	.22**	.07	.3**	.12	.3*	1				
7. Emotional Stability	.16*	.03	.19**	.29**	.35**	.49**	1			
8. Openness to Experience	.1	.07	.19**	.34**	.35**	.26**	.23**	1		
9. Age	.06	.17**	.21**	.14*	.25**	.27**	.24**	.06	1	
10. Sex	.06	−.04	−.01	−.07	−.18**	−.06	.08	−.16**	−.05	1
11. Politics	.12	.07	−.07	−.03	−.1	−.13	.07	−.24**	.01	.19**

* $p < .05$, ** $p < .01$

and whole milk). The second set of items (Study 5) was cheese items. A second goal was to predict product identification accuracy with the MLS. In this way, we can provide criterion validity for the MLS and identify a factor that is related to milk product literacy (i.e., correct identification of products).

Study 4

Participants

One hundred and twenty-five participants were recruited from Amazon's Mechanical Turk.

Materials

For the product identification tasks, participants were presented with a set of images of commercially available milk products. We selected 4 images of animal-based milk products and 4 images of plant-based milk products. There was one between-subjects condition. In one condition, participants received 4 animal-based and 2 plant-based images. In the other condition, participants received 2 animal-based and 4 plant-based images. The plant-based images included almond milk, coconut milk, rice milk, and soy milk. The animal-based images included 1% milk, 2% milk, skim milk, and whole milk. An example image for each animal-based and plant-based products is included in Appendix 3 (all images are available from the authors upon request). All six images were presented at once on the screen. Participants were instructed to select the items that were made with real cow's milk by clicking on the image. After completing the product identification task, participants completed the MLS and basic demographic information was gathered.

Results and Discussion

The different number of images did not reliably influence identification accuracy of plant-based images F (1, 124) = 0.8, $p = .78$, $\eta^2 < .001$ or animal-based images F (1, 124) = 1.82, $p = .18$, $\eta^2 = .02$. Because there was no reliable difference with respect to the number of images used, we did not include the number of images as a factor in subsequent analyses. Scores for correct product identification were combined for each of the plant-based and animal-based products for subsequent analyses.

We analyzed whether participants were reliably different from chance at identifying products (chance = 0.5). Participants were substantially better than chance at identifying animal-based products (77%, t(1,124) = 8.83, $p < .001$, $d = 0.79$) and plant-based products (94%, t(1, 124) = 30.74, $p < .001$, $d = 2.75$.

Participants were reliably better at identifying plant-based based items compared to animal-based items, t(1, 124) = 6.76, $p < .001$, $d = .61$. Participants were also reliably better on the Soy subscale of the MLS ($M = 3.54$, $SD = 1.73$) than they were on the Milk subscale of the MLS ($M = 2.05$, $SD = 1.33$), t(125) = 8.32, $p < .001$, $d = 0.74$ (but again, this result should be taken with caution).

The correlations among the variables are reported in Table 4. The Soy subscale of the MLS was a significant predictor of product identification accuracy, suggesting criterion validity for the Soy subscale.

Table 4 Correlations from Study 4 and 5

	Study #	1	2	3	4	5	6
1. Plant-based ID	4	1					
	5	1					
2. Animal-based ID	4	.52**	1				
	5	−.04	1				
3. Soy MLS	4	.24**	.22*	1			
	5	−.12	−.14	1			
4. Milk MLS	4	.08	.05	.16	1		
	5	.01	−.09	.08	1		
5. Age	4	.08	.27**	.1	.11	1	
	5	.04	.05	.13	.12	1	
6. Sex	4	−.12	−.14	−.17	.01	−.13	1
	5	.02	.11	−.2*	−.21*	−.06	1
7. Politics	4	.37**	−.28**	−.18*	−.05	−.22*	.14
	5	.03	.21*	−.34**	−.1	−.05	.25**

* $p < .05$, ** $p < .01$

Study 5

Participants

One hundred and twenty-five participants were recruited from Amazon's Mechanical Turk.

Materials

The procedure used in Study 4 was used in Study 5. Participants were presented with either 4 or 2 animal-based cheese items along with 2 or 4 plant-based cheese items at one time on a screen. The plant-based images included vegan cheddar cheese, vegan cream cheese, vegan nacho sauce, and vegan cheese slices. The animal-based images included cheddar cheese, cheese dip, cream cheese, and swiss cheese. Example items are included in Appendix 3 (all images available upon request). Participants were asked to identify which of the 6 images were made from "real cow's milk" by clicking on the image of the product. After completing the product identification task, participants answered the 12-item MLS and basic demographic information was collected.

Results and Discussion

The number of images did not reliably influence accuracy for animal-based items (t (1, 123) = .01, $p = .99$, $d = .002$) or plant-based (t (1, 123) = 0.53, $p = .6$, $d = 0.1$) products. Number of images was therefore excluded as a factor in subsequent analyses. A total correct answer score was calculated for each of the plant-based and animal-based products and used in subsequent analyses.

Participants were reliably better than chance (= 0.5) at identifying plant-based cheese items (90% accurate, t (1, 124) = 22.87, $p < .001$, $d = 2.05$) and animal-based cheese items (64% accurate, t(1, 124) = 5.43, $p < .001$, $d = .49$). Participants were reliably better at identifying plant-based compared to animal-based cheese items, t (1, 124) = 8.08, $p < .001$, $d = 0.72$. Participants were also better on the Soy subscale of the MLS ($M = 2.95$, $SD = 1.33$) than they were on the Milk subscales of the MLS ($M = 1.82$, $SD = 1.36$), $t(125) = 6.89$, $p < .001$, $d = 0.62$.

Correlations were calculated (see Table 4). In this case, there were no reliable predictors of performance on the cheese product identification task.

Nutrition Identification

A separate concern about consumer product literacy is whether using ‘milk’ terms for both animal and plant-based products causes nutritional confusion. Studies 6 and 7 were designed to test the extent to which people are confused about the nutritional content of plant-based and animal-based milk items. If using ‘milk’ terms for both kinds of items causes confusion, then there should be substantial errors when people compare the nutritional content of plant-based and animal-based milk products.

Study 6

Study 6 was designed to see how well participants could identify simple nutritional information comparing animal-based to plant-based milk items.

Participants

One hundred and twenty-five participants were recruited from Amazon’s Mechanical Turk.

Materials

We selected two paradigmatic images representing plant-based and animal-based milk: almond milk and whole cow milk (see Appendix 3 for images). These images were selected because they clearly display what kind of product they are. The clear identification of the products was aimed to help minimize the chances product confusion. We then selected several nutrition questions that were easily identified on the label of the products. We did not present nutritional labels to participants because we were interested in native nutritional knowledge of the products. The nutritional questions and instructions were (correct answers in parentheses):

Please answer the following questions about these two products. PLEASE DO NOT LOOK UP ANSWERS ONLINE. If you do not know the answer, please respond that you do not know.

1. Which product has more calories? (Milk)
2. Which product has more fat? (Milk)
3. Which product has more cholesterol? (Milk)
4. Which product has more sodium? (Almond)
5. Which product has more protein? (Milk)
6. Which product has more fiber? (Almond)
7. Which product has more sugars? (Milk)

We also used three environmental impact questions. These questions were used to estimate the extent to which people know about the relative contribution to environmental problems of each product. While these are not explicitly about nutrition, they are related to general health concerns that people might have (see for more information, see Ho et al. (2016)).

8. *Which product uses more water? (Almond)*
9. Which product generates more waste? (Milk)
10. Which product has a larger carbon footprint? (Milk).

For each question, participants were allowed to select one of the two images and were also allowed to select that they did not know. Correct answers were coded as '1'. Incorrect answers and "I don't know" responses were coded as '0'.

Participants then completed the MLS, the General Nutrition Scale used in Study 3, and basic demographic information was gathered. The General Nutrition scale was used in this study because participants were asked specifically about the nutritional content of plant-based and animal-based milk products. To further help establish validity of the MLS, we intended to estimate whether the MLS predicted accuracy on the nutrition identification task beyond the predictive ability of the General Nutrition Scale.

Results and Discussion

IRT analysis indicated that 3 items from the nutrition identification task had reverse discrimination (Items 4, 5, and 8). Those items were eliminated from analysis. Another IRT analysis was conducted on the remaining 7 items. All items had acceptable discrimination (> 0.43) and a range of difficulties (−1.74 to 0.1). A 2-parameter model had an acceptable fit to the data (all residuals on the margin had chi-squared <3.5). So, a composite score of the 7-items were calculated. The resulting scale was roughly normal ($M = 4.47$, $SD = 1.76$, $skewness = -.51$, $kurtosis = -0.24$). On average, participants could answer 64% the questions correctly. Item-level correct answers were: Calories 71%, Fat 85%, Cholesterol 70%, Fiber 67%, Sugars 48%, Waste 64%, and Carbon Footprint 61%.

Consistent with previous studies, participants were reliably more knowledgeable on the Soy subscale of the MLS ($M = 3.3$, $SD = 1.84$) than they were on the Milk subscale of the MLS ($M = 1.94$, $SD = 1.47$), $t(125) = 7.52$, $p < .001$, $d = .67$.

We were also interested in predicting performance on the Milk Nutrition Identification task. To do so, we calculated correlations among the variables (see Table 5).

Again, the Soy subscale of the MLS was a reliable predictor of correct responses to the Nutrition Identification Task suggesting criterion validity. To determine the unique predictive ability of the Soy subscale of the MLS, we used a stepwise multiple regression with the total score on the Nutrition Identification Task as the outcome variable and MLS Soy, MLS Dairy, Nutrition Knowledge, Sex, Age, and Politics as predictor variables (see Table 6).

The Soy subscale of the MLS was the strongest predictor of correct responses to the Nutrition Identification Task suggesting that the Soy subscale of the MLS is a unique predictor of nutrition identification accuracy.

Study 7

Study 7 was designed to estimate how well people could identify nutritional information about plant-based and dairy-based cheese items.

Table 5 Correlations from Study 6 and 7

	Study #	1	2	3	4	5	6	7
1. Product Nutrition ID	6	1						
	7	1						
2. MLS Soy	6	.5**	1					
	7	.24**	1					
3. MLS Milk	6	.26**	.28**	1				
	7	.16	.21*	1				
4. Nutrition	6	.45**	.58**	.33**	1			
	7	.18*	.47**	.33**	1			
5. Numeracy	6	−.02	−.09	.02	.19*	1		
	7	0	0	.13	.13	1		
6. Age	6	0	.08	.07	.27**	.02	1	
	7	0	.1	−.01	.16	−.06	1	
7. Sex	6	−.36**	−.24**	−.02	−.19*	.13	−.1	1
	7	.07	−.13	−.04	−.21*	.07	−.09	1
8. Politics	6	−.2*	−.17	0	−.17	−.04	.06	.11
	7	−.1	−.09	.07	−.25**	−.07	−.02	.14

Participants

One hundred and thirty-four participants were recruited from Amazon's Mechanical Turk.

Materials

The same general approach that was used in Study 6 was used in Study 7 except that cheese images were used instead of milk images. We selected two paradigmatic images that represent animal-based and plant-based cheese items. One image depicted a Daiya plant-based cheese product and the other image depicted an animal-based cheese product (See Appendix 3). Participants answered the following questions about each pair of images:

Please answer the following questions about these two products. PLEASE DO NOT LOOK UP ANSWERS ONLINE. If you do not know the answer, please respond that you do not know.

1. Which product has more calories per slice? (Daiya)
2. Which product has more fat per slice? (Daiya)

Table 6 Stepwise Regression from Study 6

Model #	Predictor	β	Adjusted R^2	F	P	R^2_{Change}	F_{change}	P F_{change}
1	MLS Soy	.48**	.22	36.42	< .001	..22	36.42	< .001
2	MLS Soy	.31**	.27	24.17	< .001	.06	9.42	.003
	Nutrition	.29**						
3	MLS Soy	.28**	.29	18	< .001	.03	4.34	.04
	Nutrition	.27**						
	Sex	−.16*						

** $p < .01$, * $p < .05$

3. Which product has more cholesterol per slice? (Milk)
4. Which product has more sodium per slice? (Milk)
5. Which product has more protein per slice? (Milk)
6. Which product has more calcium per slice? (Milk)
7. Which product has more sugars per slice? (Milk)
8. Which product uses more water per slice? (Milk)
9. Which product generates more waste per slice? (Milk)
10. Which product has a larger carbon footprint per slice? (Milk).

Participants could select one of the two images or indicate that they did not know. Participants also complete the MLS, the Nutrition Knowledge scale, and basic demographic information was gathered. Correct answers were coded as '1'. Incorrect answers and "I don't know" responses were coded as '0'.

Results and Discussion

IRT analysis showed that two of the Cheese Nutrition Identification items had reverse discrimination (Items 1 and 2). Those items were eliminated from analyses. After excluding those items, a 2-parameter IRT model found acceptable fit to the data (all residuals on the margins had chi-squared values <3.5). A total score for the remaining 8 items was calculated and used in analysis. On average, participants knew the correct answer for 55% of the statements (M = 4.42, SD = 2.09). Item level descriptive statistics were: Cholesterol 62%, Sodium, 49%, Protein 49%, Calcium 50%, Sugars 50%, Water 43%, Waste 64%, Carbon Footprint 60%.

Again, participants were reliably better at the Soy subscale of the MLS ($M = 3.37$, $SD = 1.78$) than they were at the Milk subscale of the MLS ($M = 1.74$, $SD = 2.05$), $t(134) = 6.92$, $p < .001$, $d = 0.6$.

Correlations among the variables are reported in Table 4. The Soy subscale of the MLS was a reliable predictor of performance on the Cheese Nutrition Identification task, suggesting criterion validity. We also performed a stepwise regression using performance on the Cheese Nutrition Identification task as the outcome variable and using the MLS Soy, MLS Dairy, Nutrition Knowledge, Sex, Age, and Politics as predictor variables. The only significant predictor of performance on the Cheese Nutrition Identification task was the Soy subscale of the MLS $t(1, 132) = 2.89$, $p = .005$, $\beta = .24$.

Replication and Modeling

The final study in the planned series of studies was to replicate the findings of Studies 1–7 in a larger sample drawn from a different sampling service. Mechanical Turk data are generally reliable for many tasks, but there are some known issues with data collected from Mechanical Turk including non-naiveté and inattentiveness (Buhrmester et al. 2011, 2018a, b; Chandler et al. 2014; Thomas and Clifford 2017). To help alleviate worries associated with biases in MTurk samples, we collected a sample using Qualtrics participants panel (see Qualtrics.com for more information).

Study 8

Participants

One thousand one hundred and eighty participants were recruited from Qualtrics testing service (see Qaultrics.com for more information about their panel services). For analyses, 126 participants were excluded for straight-lining responses (see below) leaving 1054 participants.

Materials

We used all of the finalized instruments from Studies 1–7 with some slight modifications. For the product identification tasks, we used 8 milk images (4 plant-based and 4 animal-based) and 8 cheese images (4 plant-based and 4 animal-based). Participants were given each set of images on 2 separate screens and the images were presented in random order. The participants were given the following instructions: "Please drag the items made with cow's milk into the 'milk' box and the items not made with cow's milk into the 'non-milk' box." There were two boxes on screen labeled "cow's milk" or "non-cows' milk." Participants were required to drag the images to one of the two boxes. Number of correct responses was calculated for each of cow's milk and non-cow's milk. Participants completed the modified Nutrition Identification Task from studies 6 and 7 (i.e., eliminating the items that had reverse discrimination). The 4 identification tasks were counterbalanced for order.

Participants were given the final version of the MLS, the Nutrition Knowledge scale, and the TIPI. Participants were also given the Knowledge of Animals as Food scale (KAFS) (Feltz and Feltz 2019). The KAFS is a 9-item measure of how much people know about animals used as food. The KAFS has been shown to be related to general food decisions and related to a reduction in consuming animal products. We predicted the KAFS would predict accuracy in the product identification tasks. The Berlin Numeracy Test (BNT) was included as a general measure of numeracy (Cokely et al. 2012). Numeracy has been related to normatively correct decisions in a host of domains and is associated with increased usage of accuracy conducive meta-cognitive heuristics (e.g., double checking, reframing) (Ghazal et al. 2014; Petrova et al. 2017). We hypothesized that the BNT would be positively related to correct responses in the identification tasks. Finally, basic demographic information was gathered.

Results and Discussion

An inspection of the descriptive statistics revealed some problematic aspects of some of the responses. In particular, there were a large number of zeros for the total score for the Nutrition Knowledge Scale. Otherwise, the distribution of results for the Nutrition Knowledge Scale was normal. This pattern of results was unlike the results obtained in the instrument's original validation and unlike the pattern of results observed in previous studies we conducted. Further investigation of this deviant pattern revealed a number of "straight-lined" responses—many participants answered "Don't know" to all of the nutrition questions, even questions that previous research suggested were very easy (Dickson-Spillmann et al. 2011). Those who straight-lined responses to the Nutrition Knowledge Scale also appeared to straight-line responses on other instruments. These patterns of responses suggested that some participants were not attentive or rushed through the survey. Following established practice after identifying straight-lined response (Leiner 2016), we eliminated those who answered every question of the Nutrition Knowledge Scale "I don't know" ($N = 126$).[4]

The MLS Scale A unidimensionality test of the full MLS suggested that unidimensionality could be rejected: observed second eigenvalue = 1.97, average second eigenvalue in 200 Monte Carlo samples = 0.58, $p = .005$. Tests for unidimensionality were conducted on each of the MLS subscales: Soy observed second eigenvalue = .55, average eigenvalue of 200 Monte Carlo samples = .30, $p = 0.005$; Milk observed second eigenvalue = 0.68, average of second eigenvalue in 200 Monte Carlo samples = .57, $p = .03$. While the test for unidimensionality was significant for the two subscales, the second eigenvalues were substantially less than the second eigenvalue observed for the full scale. Plus, with the increased power of the study, conventionally significant results are likely to be detected even if the second eigenvalues were small. So, we proceeded by assuming that the MLS consisted of two unidimensional subscales.

Next, we performed IRT analyses on the Soy subscale of the MLS. A one-parameter unconstrained model ($AIC = 7656.49$, BIC 7691.21) was a better fit to the data that a one-parameter constrained model ($AIC = 7660.99$, BIC 7690.75), $p = .01$. A 2-parameter model (AIC 7647.52, $BIC = 7707.06$) was a better fir to the data than a 1-parameter unconstrained model, $p = .002$ (item difficulty and discrimination are provided in Table 2). The 2-parameter model had largely good fit to the data—the chi squared values for the residuals of the margins were largely in the acceptable range (< 3.5). Two items were involved with chi-squared values larger than 3.5—items 5 and 3 (= 4.36) suggesting that in this study, the model did not fit those items particularly well.

The same IRT analyses were conducted on the Milk subscale of the MLS. A one-parameter unconstrained model ($AIC = 6755.58$, $BIC = 6790.3$) was a better fit to the data than a one-parameter constrained model ($AIC = 6777.58$, BIC 6807.34), $p < .001$. A 2-parameter model ($AIC = 6639.88$, $BIC = 6699.4$) had a better fit to the data than a 1-parameter unconstrained model, $p < .001$ (item difficulty and discrimination are provided in Table 2). The 2-parameter model had largely good fit to the data. The chi-squared values for the residuals of the margins were largely in the acceptable range (< 3.5). One item was involved in residuals greater than 3.5 (item 10).

As observed in previous studies, participants knew more on the Soy subscale ($M = 3.62$, SD = 1.61) than the Milk subscale ($M = 1.69$, $SD = 1.52$), t (1, 1053) = 32.59, $p < .001$, $d = 1$.

Product Identification Tasks The identification tasks were counterbalanced for order (i.e., each task occurred in only 1 of the 1, 2, 3, of 4th spot). The first step in the analysis was to test for orders effects. Each of the product identification tasks was entered as the dependent variable and the order of presentation was used as the independent variable. There were no order effects for the two milk product identification tasks: Plant-based milk $F(1, 1050) = 2.02$, $p = .1$, $\eta^2 = .006$, Animal-based milk $F(1, 1050) = 1.86$, $p = .17$, $\eta^2 = .005$. There were statistically significant order effects for the two cheese product identification tasks: plant-based cheese $F(1, 1050) = 2.86$, $p = .04$, $\eta^2 = .008$, animal-based cheese $F(1, 1050)) = 4.47$, $p = .004$, $\eta^2 = .01$. Even though responses to the two cheese product identification tasks displayed a

[4] We conducted analyses without excluding participants who straight-lined. As expected, including those participants did not change the results drastically, but they did mute effects making some of the effects more difficult to detect. This pattern is exactly what would be expected given straight-lined responses.

statistically significant order effect, the magnitude of the effect was small. Because of the small effect sizes and for simplicity of analyses, we did not include order as a factor in subsequent analyses.

Participants were better than chance (chance = 2) at identifying all products: Animal-based milk ($M = 3.65$, $SD = 0.64$ $t(1, 1053) = 83.38$, $p < .001$, $d = 2.57$; plant based milk ($M = 3.24$, $SD = 1.25$) $t(1, 1053) = 32.36$, $p < .001$, $d = 0.99$; plant based cheese ($M = 2.82$, $SD = 1.08$) $t(1, 1053) = 24.55$, $p < .001$, $d = 0.76$; and animal based cheese ($M = 3.31$, $SD = 0.85$) $t(1, 1053) = 49.78$, $p < .001$, $d = 1.53$. In this study, participants were better at identifying animal based milk products $t(1, 1053) = 9.85$, $p < .001$, $d = 0.3$ and animal based cheese products $t(1, 1053) = 12$, $p < .001$, $d = 0.37$.

Nutrition Identification No order effect was found for either the milk nutrition identification task ($F(3, 1050) = 0.83$, $p = .48$, $\eta^2 = .002$) or cheese nutrition identification task ($F(3, 1050) = 0.05$, $p = .99$, $\eta^2 = 0$). People were generally better at identifying milk nutrition items ($M = 4.29$, $SD = 1.9$, 61% correct) compared to cheese nutrition items ($M = 3.61$, $SD = 2.21$, 45% correct), $t(1053) = 19.29$. $p < .001$, $d = .59$.

Item level statistics were calculated for each question. For the milk nutrition items, the following were the percent of correct responses: Calories 69%, Fat 22%, Cholesterol 40%, Fiber 64%, Sugars 44%, Waste 47%, and Carbon Footprint 47%. For the cheese questions, the following percent responded correctly: Cholesterol 62%, Sodium, 51%, Protein 37%, Calcium 46%, Sugars 44%, Water 30%, Waste 46%, Carbon Footprint 43%.

Correlations among all the dependent variables are reported in Table 7.

Path Analyses We used path analyses to estimate relations among key variables measured. The primary outcome variable of interest was the performance on the identification tasks. We randomly divided the data into 2 groups: a test set ($N = 508$) and a validation set ($N = 546$). We formulated path models based on the correlations observed in the studies and previous research on skilled decision making (Cokely et al. 2018). We tested and refined the models on the test set. The modified path models were then tested again on the validation set. Path models for the test and validation sets for the product identification tasks are in Figs. 1 and 2. Path models for the nutrition identification tasks are in Fig. 3. All but one of the models passed conventional fit criteria. The models had the following test statistics.

Animal-Based Milk Product Identification The test set model passed conventional fit criteria: χ^2 (2) = 1.31, $p = .52$, $RMSEA = 0$, $90\%\ CI = 0–.08$, $pclose = .81$, $CFI = 1$, $TLI = 1$. The validation set model also passed conventional fit criteria: χ^2 (2) = 0.74, $p = .69$, $RMSEA = 0$, $90\%\ CI = 0–0.6$, $pclose = .9$, $CFI = 1$, $TLI = 1$. All indirect paths were significant ($p < .05$).

Plant-Based Milk Product Identification The test set model passed conventional fit criteria: χ^2 (2) = 2.35, p = .31, $RMSEA = .02$, 90% CI 0–0.9, $pclose = .66$, $CFI = 1$, $TLI = .99$. The validation set model also passed conventional fit criteria: χ^2 (2) = 0.76, $p = .69$, $RMSEA = 0$, 90% CI 0–0.6, $pclose = .9$, $CFI = 1$, $TLI = 1$. All indirect paths were significant ($p < .05$).

Animal-Based Cheese Product Identification The test set model passed conventional fit criteria: χ^2 (2) = 0.71, $p = .7$, $RMSEA = 0$, $90\%\ CI =$ 0–.07, $pclose = .9$, $CFI = 1$, $TLI = 1$. The validation set model also passed conventional fit criteria: χ^2 (2) = 1.11, $p = .57$, $RMSEA = 0$, $90\%\ CI =$ 0–.07, $pclose = .85$, $CFI = 1$, $TLI = 1$. All indirect paths were significant ($p < .05$).

Table 7 Correlations from Study 8

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Animal Milk ID	1																	
2. Plant Milk ID	.11**	1																
3. Animal Cheese ID	.28**	.18**	1															
4. Plant Cheese ID	.16**	.42**	.08**	1														
5. Milk Nutrition	.08*	.14**	.07*	.14**	1													
6. Cheese Nutrition	−.05	−.01	−.05	..51**	.5**	1												
7. MLS Soy	.09**	.16**	0	.1**	.39**	.33**	1											
8. MLS Dairy	0	−.05	.16**	0	.13**	.13**	.24**	1										
9. Nutrition	.16**	.3**	.16**	.22**	.27**	.21**	.4**	.29**	1									
10. KAFS	.17**	.34**	.19**	.27**	.18**	.04	.17**	−.02	.35**	1								
11. Extraversion	0	−.02	−.06	−.08**	.03	.06	.07*	.05	.05	−.04	1							
12. Agreeableness	.08*	.15**	.03	.13**	.07	.01	.11**	−.04	.15**	.18**	−.08*	1						
13. Conscientious	.06*	.18**	.04	.12**	.1**	.04	.11**	−.05	.18**	.19**	.11**	.32**	1					
14. Emotional	.03	.05	0	.04	.06*	.04	.09**	.02	.11**	.05	.1**	.36**	.39**	1				
15. Openness	.06*	.13**	.05	.08**	.13**	.09**	.09**	−.01	.12**	.16**	.16**	.32**	.28**	.2**	1			
16. Age	.06*	.21**	.07*	.15**	−.03	−.08**	.12**	−.03	.25**	.18**	.04	.26**	.28**	.28**	.01	1		
17. Gender	−.1**	−.1**	−.06*	.06	−.04	.05	−.05	.02	−.13**	−.14**	−.02	−.09*	−.03	.05	−.07*	.02	1	
18. Politics	.05	.05	.01	.05	.04	−.01	.01	−.08*	−.03	−.06*	−.01	0	.07*	.01	−.1**	.12**	−.01	1
19. Numeracy	.17**	.23**	.19**	.19**	.07*	−.04	.13**	.05	.31**	.22**	−.05	.1**	.15**	.07*	.06*	.1**	.13**	.01

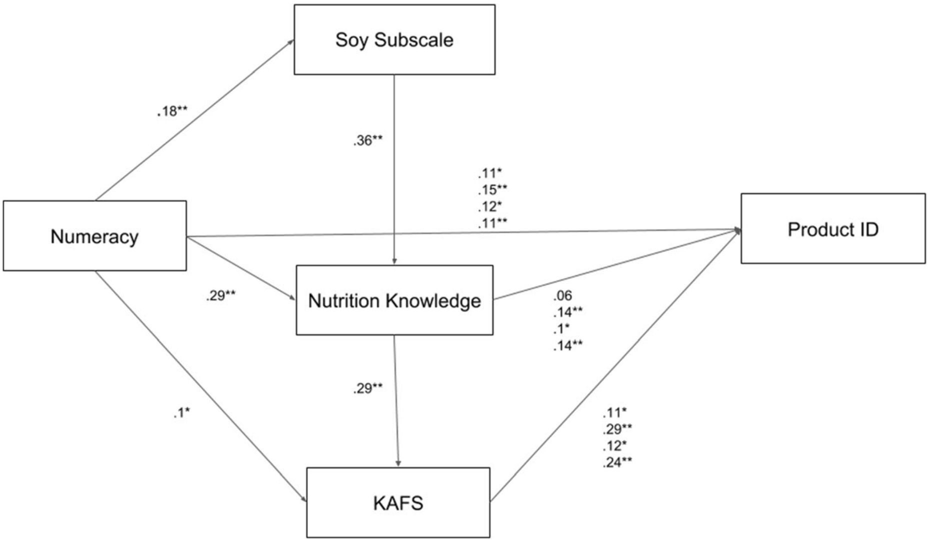

Fig. 1 Path Model of Product Identification in the Test Sample. The paths with one path coefficient were identical in all models because the same sample was used. The paths predicting the product identification were in the following order from first to last path coefficient: Animal-based Milk Product ID, Plant-based Milk Product ID, Animal-based Cheese Product ID, Plant-based Cheese Product ID. All significant paths are marked * <. 05, ** < .01

Plant-Based Cheese Product Identification The test set model passed conventional fit criteria: χ^2 (2) = 0.65, $p = .72$, $RMSEA = 0$, $90\%\ CI = 0–0.6$, $pclose = .91$, $CFI = 1$, $TLI = 1$.

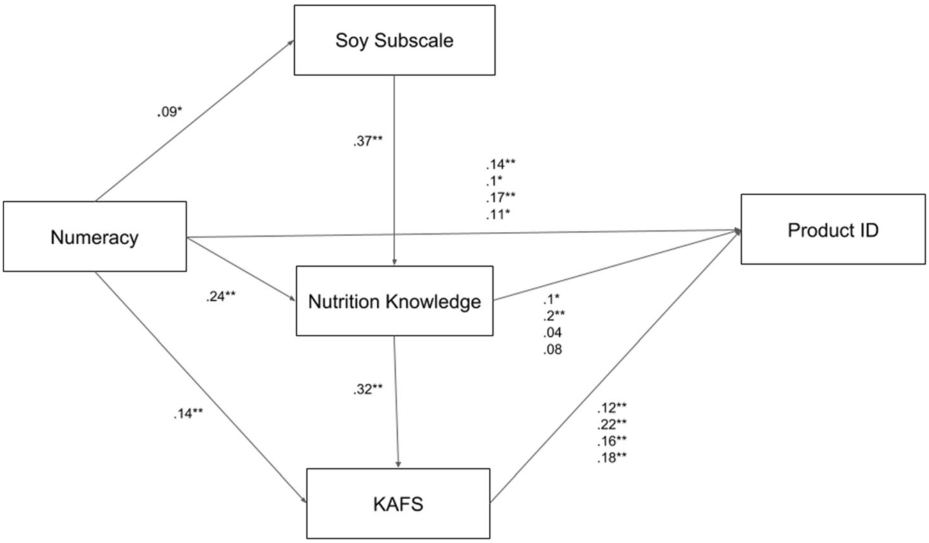

Fig. 2 Path Model of Product Identification in the validation sample. The paths with one path coefficient were identical in all models because the same sample was used. The paths predicting the product identification were in the following order from first to last path coefficient: Animal-based Milk Product ID, Plant-based Milk Product ID, Animal-based Cheese Product ID, Plant-based Cheese Product ID. All significant paths are marked * <. 05, ** < .01

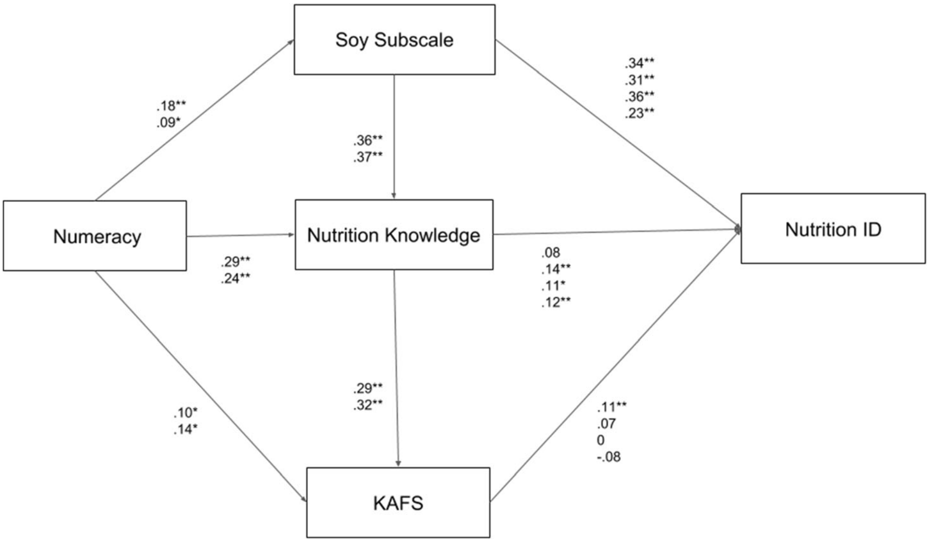

Fig. 3 Path Model of the Nutrition Identification in the Test Sample and validation samples from Study 8. The paths with two path coefficients reflect the values from the test set and validation set (respectively). The paths with 4 path coefficients reflect the results in order: Milk nutrition identification test set, validation set, cheese nutrition identification test set, and validation set. All paths from the hypothesized models were included, significant paths were are marked * < . 05, ** < .01

The validation set model also passed conventional fit criteria: χ^2 (2) = 0.75, p = .69, *RMSEA* = 0, *90% CI* = 0–.06, *pclose* = .9, *CFI* = 1, *TLI* = 1. All indirect paths were significant ($p < .05$).

Milk Nutrition Identification The test set model passed conventional fit criteria: χ^2 (2) = 0.8, p = .67, *RMSEA* = 0, *90% CI* = 0–.07, *pclose* = .88, *CFI* = 1, *TLI* = 1. The validation set model also passed conventional fit criteria: χ^2 (2) = 1.49, p = .48, *RMSEA* = 0, *90% CI* = 0–.08, *pclose* = .8, *CFI* = 1, *TLI* = 1. All indirect paths were significant ($p < .05$).

Cheese Nutrition Identification The test set model passed conventional fit criteria: χ^2 (2) = 4.93, p = .08, *RMSEA* = .05, *90% CI* = 0–.12, *pclose* = .36, *CFI* = .99, *TLI* = .95. The validation set model, however, did not pass conventional fit criteria: χ^2 (2) = 10.44, p = .005, *RMSEA* = .09, *90% CI* = .04–.14, *pclose* = .09, *CFI* = .97, *TLI* = .84. All indirect paths were significant ($p < .05$) except for the BNT → Cheese Nutrition indirect path, p = .06.

Policy Implications

The results of the eight studies suggested that people are often product literate enough to reliably distinguish plant-based products from animal-based products. People also generally understand nutritional differences among plant-based and animal-based products.

To help further illustrate people's milk product literacy, there were some notable differences among the studies. Studies 4 and 5 suggested that people are generally better at identifying plant-based milk products and study 8 suggested that they were better at identifying animal-based milk products. To help address the conflicting results, we meta-analytically combined the percentage of correct responses and tested for differences using plant-based v. animal-based products as a moderator. Concerning milk products, there was no significant moderator effect between animal-based (84%) and plant-based (88%) product identification accuracy, $z = 0.37$, $p = .71$. A similar pattern was found for cheese product identification accuracy. People were no better at identifying animal-based (81%) cheese products compared to plant-based (74%) cheese products, $z = 0.52$, $p = .6$.

The evidence suggests that participants in general have the ability to identify plant-based and animal-based 'milk' products. As the meta-analytic estimates suggest, people identify products correctly between 74% and 88% of the time. While this is not 100% accuracy, it is unreasonable to expect 100% accuracy. There are many reasons why one would make a mistake including simple performance errors (clicking on the wrong item) and inattentiveness. These sources of error do not reflect a deep, systematic ignorance or lack of product literacy. If an element of product literacy is that consumers are able to understand and articulate differences among products, then it appears that people are generally product literate enough to at least distinguish plant-based from animal-based milk products.

Concerning nutritional differences, participants' accuracy was worse than their performance on product identification. To illustrate, we again meta-analytically combined the nutrition accuracy scores for Studies 5, 6, and 8. We tested whether cheese or milk nutrition tasks moderated the overall test scores. There was no overall moderator effect between the cheese and milk tasks, $z = 0.96$, $p = .34$. Overall mean correct score for milk was 4.37 (62%), *95% CI* = 3.81–4.94 and for cheese was 3.98 (50%), *95% CI* = 3.42–4.55. Hence, people tended to be roughly as good at identifying nutritional differences among milk and cheese items.

One might think that the overall scores for the nutrition identification tasks support the argument that using 'milk' terms for plant and animal-based products causes nutritional confusion. But such support is tempered for at least 3 reasons. First, the way that we coded responses to the nutritional task was that only correct answers were scored as correct and all other answers were scored as being incorrect. We adopted this scoring strategy partially to follow previous research (e.g., Cowburn and Stockley (2005)) and partially to provide the strongest test of consumer product literacy (i.e., only counting as correct those who knew the correct response). As such, this scoring method should be interpreted as a lower-bound estimate. However, one could argue that if one knows that one does not know, then that does not indicate confusion. Rather, an "I don't know" response reflects that one honestly does not know and not that one believes something that is false. So, people may not make a mistake when they respond that they do not know. If we count those who responded that they do not know as being correct, then the percentage of correct responses increases dramatically. In Study 6, 86 of 1000 (~8.6%) response were "I don't know." Similarly for Study 7, the total number of "I don't know" response was 291 of 1072 (~20%). If we included those "incorrect" responses in the "correct" response category, then people correctly responded to 72.6% of the milk nutrition questions and 75% of the cheese nutrition questions.

Second, participants were more knowledgeable about differences between plant-based and animal-based products than they were about differences between animal-based products (i.e., whole milk v. skim milk) as measured by the MLS. While this result should be interpreted with caution for the reasons we have mentioned, (e.g., items could have been selected with different difficulties between the two scales), looking at the overall pattern of results for similar questions is informative. We meta-analytically combined the results the MLS from studies 3–8 and found that on average, people were more knowledgeable on the Soy subscale ($M = 3.47$, $SE = 0.15$, *95% CI* = 3.18–3.76) than they were on the Milk subscale ($M = 1.89$, $SE = 0.07$, *95% CI* = 1.76–2.02), $d = 0.79$ ($SE = 0.08$) $z = 9.67$, $p < .001$, *95% CI* = 0.62–0.95. This result is consistent with the general ignorance about the nutritional differences among animal-based milk products (Finnell and John 2017). The results from the meta-analysis of the MLS and previous research weaken the claim that there is widespread confusion about the nutritional difference between plant-based and animal-based milk products. Or, by parity of reasoning, one should be concerned about the nutritional ignorance surrounding animal-based milk products. Restricting the usage of 'milk' terms will do nothing to alleviate the ignorance and lack of consumer product literacy that exists for animal-based milk products.

Third, our data indicate that people are not perfectly knowledgably about milk products. But that leaves open what the best interventions are for those who need help. The path models provide some important clues about how to help people make better consumer decisions. In the broadest terms, those who knew more about milk and nutrition were better at the identification tasks. That means that there are some fairly clear interventions that would likely help people become more product literate. For example, the links between animal welfare knowledge, general nutrition knowledge, and milk specific knowledge suggest that simply educating people about the facts of milk would help people make better, more informed decisions about milk products (Cokely et al. 2018; Feltz and Cokely 2017; Feltz and Feltz 2019; Garcia-Retamero et al. in press). Indeed, given the evidence presented here, simply forbidding the use of some language will not rectify issues of ignorance concerning milk. People are likely be just as product illiterate about animal-based milk products as they were before proposed restrictions on 'milk' terms.

There are a number of limitations with the current series of studies. First, the choices concerning product identification were somewhat artificial. Participants were shown images of products and asked to make decisions about them. In real environments like grocery stores, a different pattern of results may have been observed. Moreover, there could be some other, even more subtle confusions that using 'milk' terms for both animal-based and plant-based products could cause (e.g., overestimating the nutritional of quality of plant-based 'milk' products). This kind of confusion is ultimately best addressed empirically. However, given the results of our studies, the subtler confusions about plant-based milk will also likely be present in animal-based milk products. So, we are skeptical that making the argument any more nuanced will help support the central empirical claim of those who favor restricting the use of 'milk' terms only for animal products. Finally, it is important to estimate the effectiveness of educational interventions versus policy level prohibitions on consumer product literacy about milk products.

We take the last limitation as an important avenue for future research. Side-by-side estimates of the effectiveness of interventions allows comparisons in key respects (Feltz 2015; Feltz and Cokely 2017). Restricting 'milk' terms to animal-based products may be ineffective in increasing consumer milk product literacy. More than that, there maybe be important opportunity costs associated with opting for restrictions rather than education. Adopting educational programs holds the promise of increasing consume product literacy while at the same time protecting and promoting individual autonomy. Ultimately, education can empower people to make their own decisions thereby respecting and promoting people's individual autonomy along with consumer product literacy.

Appendix 1

Items used in Study 1. Correct answer in parentheses. Difficulty and discrimination, respectively, in brackets.

Soy Subscale

1. Whole cow milk has more cholesterol than fortified soy milk. (T) [−9.1, 0.17]
2. Whole cow milk has more protein than fortified soy milk. (F) [−0.23, −1.5]
3. Whole cow milk has more Vitamin C than fortified soy milk. (T) [0.31, 1.62]
4. Whole cow milk has more calories than fortified soy milk (T) [−3.4, 0.5]
5. Whole cow milk has more fat than fortified soy milk. (T) [−4.54, 0.47]
6. Whole cow milk has more fiber than fortified soy milk. (F) [0.44, −1.58]
7. Whole cow milk has more sodium than fortified soy milk. (T) [−0.37, 0.82]
8. Whole cow milk has more iron than fortified soy milk. (F) [−0.03, −2.4]
9. Whole cow milk has more saturated fat than fortified soy milk. (T) [−6.61, 0.3]
10. Whole cow milk has more calcium than fortified soy milk. (T) [−0.33, 1.66]
11. Whole cow milk has more carbohydrates than fortified soy milk. (T) [−0.92, 0.85]
12. Whole cow milk has more lactose than fortified soy milk. (T) [−4.86, 0.29]
13. Cow milk and fortified soy milk have all the same nutrients. (F) [1.63, −0.61]

Milk Subscale

14. Whole cow milk has more protein than skim cow milk. (F) [0.71, 1.48]
15. Whole cow milk has more fat than skim cow milk. (T) [12.85, −0.18]
16. Whole cow milk has more calories than skim cow milk. (T) [14.22, −0.18]
17. Whole cow milk has more calcium than skim cow milk. (F) [0.36, 2.62]
18. Whole cow milk has more Vitamin C than skim cow milk. (F) [−0.19, 2.36]
19. Whole cow milk has more sodium than skim cow milk. (F) [0.26, 1.59]
20. Whole cow milk has more fiber than skim cow milk. (F) [0.4, 2.11]
21. Whole cow milk has more cholesterol than skim cow milk. (F) [2.71, 0.81]
22. Whole cow milk has more iron than skim cow milk. (F) [0.39, 2.11]
23. Fortified soy milk is made with some cow milk. (F) -1.51, 0.62]

Appendix 2

Items used in Studies 2. Items removed from Studies 3–8 in italics.

Soy Subscale

1. *Whole cow milk has more Vitamin C than fortified soy milk. (T)*
2. Whole cow milk has more calories than fortified soy milk (T)
3. Whole cow milk has more fat than fortified soy milk. (T)
4. *Whole cow milk has more sodium than fortified soy milk. (T)*
5. Whole cow milk has less saturated fat than fortified soy milk. (F)

6. Whole cow milk less more calcium than fortified soy milk. (F)
7. Whole cow milk has fewer carbohydrates than fortified soy milk. (F)
8. Whole cow milk has less lactose than fortified soy milk. (F)

<u>Milk Subscale</u>

9. Whole cow milk has more protein than skim cow milk. (F)
10. Whole cow milk has more calcium than skim cow milk. (F)
11. *Whole cow milk has more Vitamin C than skim cow milk. (F)*
12. Whole cow milk has more sodium than skim cow milk. (F)
13. *Whole cow milk has more fiber than skim cow milk. (F)*
14. Whole cow milk has more cholesterol than skim cow milk. (F)
15. Whole cow milk has more iron than skim cow milk. (F)
16. Fortified soy milk is made with some cow milk. (F)

Appendix 3

Sample Product Identification Milk Items

Sample Product Identification Cheese Items

Milk Nutrition Identification Items

Cheese Nutrition Identification Items

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Exhibit 2

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Article

Environmental Impact of Two Plant-Based, Isocaloric and Isoproteic Diets: The Vegan Diet vs. the Mediterranean Diet

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Abstract: Food consumption is one of the major causes of climate change, resource depletion, loss of biodiversity, and other kinds of environmental impact by modern households. According to evidence, a global change in dietary habits could be the single most effective and rapid intervention to reduce anthropic pressure on the planet, especially with respect to climate change. Our study applied Life Cycle Assessment (LCA) to investigate the total environmental impact of two plant-based diets: the Mediterranean and the Vegan diets, according to relevant Italian nutritional recommendations. The two diets share the same macronutrient rates and cover all the nutritional recommendations. Calculations were made on the basis of a theoretical one-week 2000 kcal/day diet. According to our calculations, the Vegan diet showed about 44% less total environmental impact when compared to the Mediterranean diet, despite the fact that the content of animal products of the latter was low (with 10.6% of the total diet calories). This result clearly supports the concept that meat and dairy consumption plays a critical role, above all, in terms of damage to human health and ecosystems. Our study supports the thesis that even a minimal-to-moderate content of animal foods has a consistent impact on the environmental footprint of a diet, and their reduction can elicit significant ecological benefits.

Keywords: food system; climate change; life cycle assessment; LCA; environmental impact; sustainable diet; plant-based diets; environmental footprint

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1. Introduction

"*Sustainability is the development that meets the needs of the present, without compromising the ability of future generations to meet their own needs*" [1].

The present phase of our planet is called the "*Anthropocene*", an era in which one single species is altering the Earth's systems, causing climate change, biodiversity loss, land and water scarcity, and many other environmental issues. People are living well beyond Earth's means, cumulating an "environmental deficit" that started about 35 years ago [2], which is compromising our sustainability.

For the European Union (EU), progress towards reaching the 17 Sustainable Development Goals (SDGs) of the United Nation's 2030 Agenda for Sustainable Development, to be achieved by 2030, will require increased efforts in the optimization of food production and distribution, climate change mitigation, and resource preservation [3]. According to FAO/WHO, sustainable diets should provide "adequate, safe, diversified and nutrient rich food for all, which contribute to healthy diets" [3–5].

Some specific areas can be influenced by the food production process, i.e., desertification (water scarcity), land degradation and food security. A 2 °C global warming is deemed to increase the risk of food system instability [6].

Data from the Food and Agriculture Organization (United Nations) show that only 29% of the Earth's surface is covered with land, 71% of which is habitable. As much as 50%

of the habitable land is devoted to agriculture, of which 77% is used for animal farming, a land amount that produces only 18% of the total calorie supply [7]. With a projected world population of 9 billion people, the growing meat consumption and the use of bio-based materials and biofuels will cause an estimated increase of 70–110% in agricultural production by 2050 [8] (Figure 1).

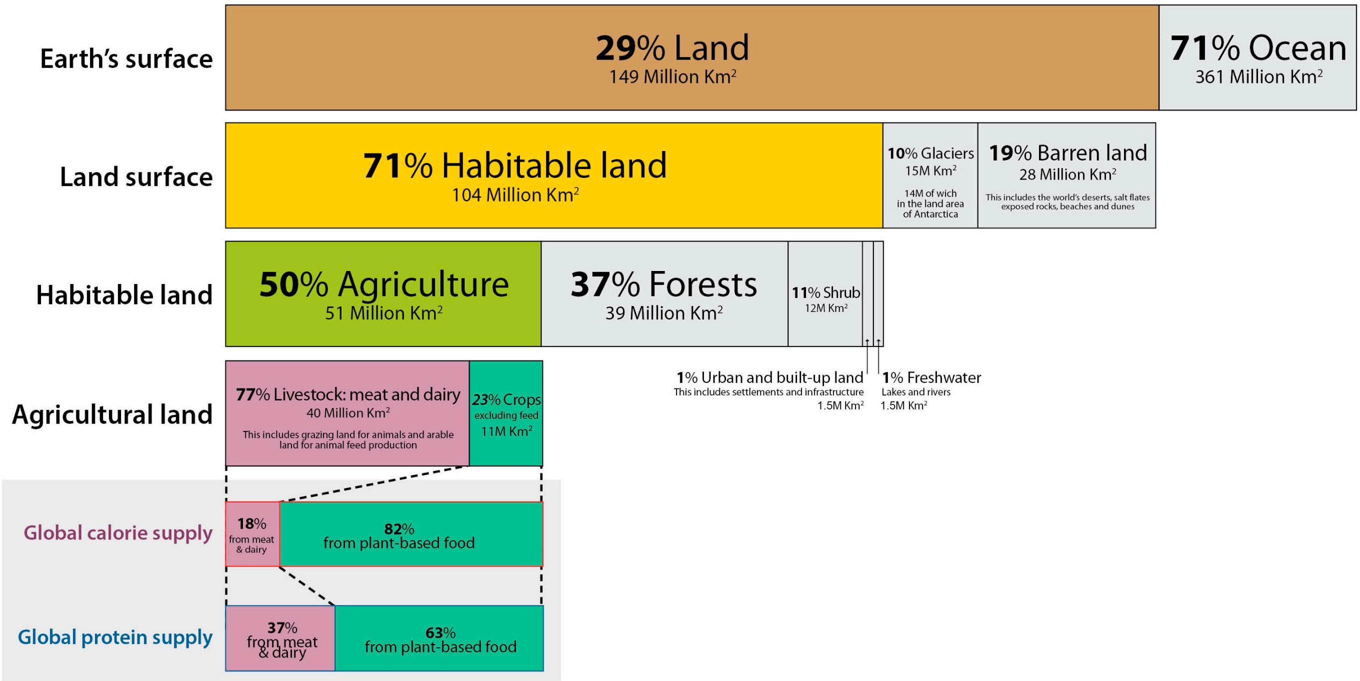

Figure 1. Land Use (Open-source under the CC-BY License) [7].

The food system is tightly bound to the environment because it relies on it for most of its primary inputs: (a) the consumption of natural resources (water, land, soil, seeds etc.), and (b) the introduction of several residual emissions into the environment, in the form of wasted food, pollutants like pesticides, drugs (e.g., antibiotics) and GHGs, which have an impact also on human health. This interrelationship is clearly complex and multidisciplinary [3].

Diets have been traditionally conceived as factors and strategies interrelated to health and well-being and influence the diet-related incidence of diseases. Diets, nevertheless, relate also to the food system, which has been recognized as a major source of environmental impact, with a close relation to several of the so-called planetary boundaries [9].

In fact, in addition to what the choices on a large scale can contribute, the choices of every single person are also important. In this context, it has been reported that individual dietary choices can help influence sustainability. Specifically, it has been demonstrated that foods of plant origin are more sustainable. Therefore, their proportion in the diet influences the total environmental impact of the diet itself. Omnivorous dietary patterns are known to have a higher impact on the environment than plant-based diets, and the amount of animal foods in the diet appears to be the major determinant of the total impact [10,11].

The original Mediterranean diet, although omnivorous, can be considered, if well planned, a plant-based diet since it emphasizes whole plant foods (vegetables, fruits, nuts, whole grains, and olive oil), despite including small amounts of animal foods (dairy, fish and poultry, and red meat) [12].

On the contrary, in the Vegan diet, all animal foods are totally absent: composition is based on grains, legumes, vegetables, fruits, nuts and oils [13].

Therefore, the only qualitative difference between the two diets is that the animal protein foods of the Mediterranean diet are replaced by protein plant foods in the Vegan diet.

Based on this principle, we aimed to evaluate if and how much a Vegan diet, with a comparable energy-nutritional composition, could represent a real advantage in terms of the total environmental impact compared to the Mediterranean diet.

We used LCA methodology to investigate the total environmental impact of the two plant-based diets by SimaPro® and Ecoinvent®, which are the most commonly used LCA software and database [14].

2. Materials and Methods

Our aim was to compare two well-planned plant-based diets, the Mediterranean and the Vegan, both healthy and environmentally friendly, to assess how they differ in their environmental impacts even though they share as many similarities as the respective guidelines consent, in terms of nutritional values and gastronomic preparations.

The two diets, which were formulated by a licensed dietician, were similar in terms of the quantity and nutritional composition of the foods consumed and were conceived to minimize "composition biases": they share the same sources of food types, the same nutrient compositions, the same recipes (where applicable), and the same amount of energy. Differences in the use of non-protein foods were reduced as much as their respective guides suggested. In the Mediterranean diet, we planned only 10.6% of its total calories are derived from animal foods, which puts it under the umbrella of the "plant-based diets".

The functional units are quantified descriptions of a product's function, used as the basis to calculate impact assessments. In our study, the functional units consist of all the "ready to eat" food products of two 2000 kcal/day "one-week diets" (Table 1a), each planned according to their respective dietary guides (Mediterranean and Vegan) and carefully developed to minimize unnecessary differences that could bias the final result.

Table 1. Vegan vs. Mediterranean diet foods.

a. Composition of the Two One-Week Diets.

Vegan			Mediterranean		
Food	**Amount**	**Unit**	**Food**	**Amount**	**Unit**
Mixed grains (cooked)	1.12	kg	Mixed grains (cooked)	1.12	kg
Rice (cooked)	0.72	kg	Rice (cooked)	0.72	kg
Pasta (cooked)	1.68	kg	Pasta (cooked)	1.68	kg
Bread	0.66	kg	Bread	0.66	kg
Olive oil	0.08	kg	Olive oil	0.14	kg
Mixed legumes (cooked)	0.88	kg	Mixed legumes (cooked)	0.40	kg
Mixed fruit	2.63	kg	Mixed fruit	2.10	kg
Vegetables (raw and cooked)	4.20	kg	Vegetables (raw and cooked)	4.20	kg
Mixed nuts	0.42	kg	Mixed nuts	0.40	kg
Sunflower oil	0.06	kg	Egg (cooked)	0.12	kg
Soy dessert, plain, refrigerated	0.25	kg	Chicken (cooked)	0.12	kg
Soy drink, plain, fortified with calcium	0.80	kg	Cheese	0.21	kg
Seitan	0.06	kg	Fish (cooked)	0.12	kg
Tofu	0.16	kg	Red meat (cooked)	0.06	kg
			Skimmed milk	1.40	kg

b. Daily Average Nutritional Characteristics of the Two One-Week Diets.

	Vegan	**Mediterranean ***
Energy (kcal)	2016.57	2018.57
Carbohydrates (%)	52.93	49.76
Proteins (%)	16.48	17.81
Fats (%)	30.55	32.46
Fiber g (total/1000 kcal)	24.14	21.09
Iron (mg)	22.52	19.27
Calcium (mg)	851.94	853.48
Zinc (mg)	12.71	12.98

* Total kcalories from animal products in a week 1500; kcalories from animal products/per day 214.28.

In our study, the Mediterranean diet was planned according to the "new revised MD pyramid representation", published in 2011 [12], whether the Vegan diet's planning derived from the Mediterranean "VegPlate" guide [13].

Due to the high-calorie density of animal foods, the quantity, in grams/day, of these products was significantly lower than in an average Western diet. Calorie and nutrient intake counts were obtained using MetaDieta® professional software, using the Italian food database [15] (Table 1b).

Recipes were simplified, avoiding unnecessary steps in their preparations in all calculations. For example, we used "mixed boiled vegetables" for all recipes containing cooked vegetables, "mixed cooked meat" (cow meat, swine meat and chicken meat) for all recipes containing meat and so on. Both diets contain the same amount of cooked grains, pasta and vegetables (both raw and cooked) but differ in the amount of fruit, nuts, oils and protein foods due to the differences in their respective guides.

Life cycle assessment (LCA) is an analytical and systematic methodology that evaluates the environmental footprint of a product or service along its entire life cycle.

We used an internationally recognized method of evaluating environmental impact (LCA): ReCiPe 2016 [16]. At the midpoint level, 18 impact categories were addressed. They were then aggregated into endpoint damage categories. Midpoints included: climate change (human health, terrestrial ecosystem and freshwater ecosystem), stratospheric ozone depletion, ionizing radiation, ozone formation (human health), fine particulate matter formation, ozone formation (terrestrial ecosystems), terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, human carcinogenic toxicity, human non-carcinogenic toxicity, land use, mineral resource scarcity, fossil resource scarcity, and water consumption (human health, terrestrial ecosystem and aquatic ecosystem). At the endpoint level, most of these midpoint impact categories are multiplied by damage factors and aggregated into three endpoint categories: human health, ecosystems, and resource [16].

In this study, Software SimaPro® was used for LCA analysis. Given the absence of an Italian national database for inventory, we used the Ecoinvent-3 library, which contains LCI data from various sectors (e.g., energy production, goods transportation, production of chemicals, metal production, fruit and vegetable production etc.). We assessed the impact of the two selected diets based on the "cradle to gate", or "farm to fork" system boundaries, which includes all the processes involved in the production of our unit (i.e., the one-week diet) up until its consumption. The system boundaries we selected included the following sub-stages: (1) agricultural food production (crops, animal husbandry), (2) transport (global), (3) processing of food products (for the general market), (4) packaging, and (5) consumption, including home preparation. Data for sub-stages 1 to 4 were derived from the Ecoinvent® database. Sub-stage 5 calculations were not provided in this paper but are available on request. Other sub-stages, such as transportation to retailers, waste, food losses and recycling, were excluded. Nevertheless, some downstream emissions, such as those that occur in food processing or preparation (e.g., kitchen gas, water, and electricity used), were included in the calculations. For example, some plant foods require longer cooking times, so their impact has been assessed in the contexts of all food system activities, from production to consumption.

3. Results

The results of the Assessment (Life Cycle Impact Assessment/LCIA)—Calculations are shown in Tables 2 and 3 and Figure 2.

Table 2. Life Cycle Assessment Calculation (LCIA), proposed for steps. (DALY: disability-adjusted life years; species.yr: loss of species during a year; USD2013: US Dollars).

a. Characterization				
Impact Category	**Unit**	**Vegan**	**Mediterranean**	**Δ Veg-Med**
Global warming, Human health	DALY	1.24×10^{-5}	1.62×10^{-5}	-0.38×10^{-5}
Global warming, Terrestrial ecosystems	species.yr	3.75×10^{-8}	4.88×10^{-8}	-1.13×10^{-8}
Global warming, Freshwater ecosystems	species.yr	1.02×10^{-12}	1.33×10^{-12}	-0.31×10^{-12}
Stratospheric ozone depletion	DALY	4.77×10^{-8}	6.23×10^{-8}	-1.46×10^{-8}
Ionizing radiation	DALY	6.13×10^{-9}	3.28×10^{-9}	2.84×10^{-9}
Ozone formation, Human health	DALY	3.08×10^{-8}	4.14×10^{-8}	-1.06×10^{-8}
Fine particulate matter formation	DALY	1.40×10^{-5}	1.85×10^{-5}	-0.45×10^{-5}
Ozone formation, Terrestrial ecosystems	species.yr	4.45×10^{-9}	5.98×10^{-9}	-1.53×10^{-9}
Terrestrial acidification	species.yr	1.75×10^{-8}	2.54×10^{-8}	-0.79×10^{-8}
Freshwater eutrophication	species.yr	2.99×10^{-9}	3.14×10^{-9}	-0.15×10^{-9}
Marine eutrophication	species.yr	2.97×10^{-11}	3.54×10^{-11}	-0.06×10^{-11}
Terrestrial ecotoxicity	species.yr	5.56×10^{-10}	5.43×10^{-10}	0.12×10^{-10}
Freshwater ecotoxicity	species.yr	5.22×10^{-10}	5.37×10^{-10}	-0.16×10^{-10}
Marine ecotoxicity	species.yr	8.87×10^{-11}	8.78×10^{-11}	0.09×10^{-11}
Human carcinogenic toxicity	DALY	1.36×10^{-6}	1.42×10^{-6}	-0.05×10^{-6}
Human non-carcinogenic toxicity	DALY	9.08×10^{-6}	32.36×10^{-6}	-23.28×10^{-6}
Land use	species.yr	1.37×10^{-7}	2.67×10^{-7}	-1.30×10^{-7}
Mineral resource scarcity	USD2013	1.64×10^{-2}	1.75×10^{-2}	-0.11×10^{-2}
Fossil resource scarcity	USD2013	8.29×10^{-1}	8.76×10^{-1}	-0.47×10^{-1}
Water consumption, Human health	DALY	1.84×10^{-6}	1.79×10^{-6}	0.06×10^{-6}
Water consumption, Terrestrial ecosystem	species.yr	1.18×10^{-8}	1.12×10^{-8}	0.06×10^{-8}
Water consumption, Aquatic ecosystems	species.yr	4.17×10^{-12}	3.89×10^{-12}	0.28×10^{-12}
b. Damage Assessment				
Damage Category		**Vegan**	**Mediterranean**	**Δ Veg-Med**
Human Health	DALY	3.88×10^{-5}	7.03×10^{-5}	-3.15×10^{-5}
Ecosystems	Species.yr	2.12×10^{-7}	3.63×10^{-7}	-1.50×10^{-7}
Resources	USD2013	0.8457	0.8933	−0.0476
c. Normalization				
Damage Category	**Unit**	**Vegan**	**Mediterranean**	**Δ Veg-Med**
Human Health	-	1.63×10^{-3}	2.96×10^{-3}	-1.33×10^{-3}
Ecosystems	-	2.96×10^{-4}	5.06×10^{-4}	-2.10×10^{-4}
Resources	-	3.02×10^{-5}	3.19×10^{-5}	-0.17×10^{-5}

Table 3. Total Environmental Impact of Vegan and Mediterranean diets: Impact Categories and Damage Categories. Aggregated Weighted Average: total environmental load expressed as a Single Score (mPt = milliPoints).

Impact Category	Unit	Vegan	Mediterranean	Δ Veg-Med	%
Global warming, Human health	***Pt***	***1.57×10^{-1}***	***2.04×10^{-1}***	***-0.47×10^{-1}***	***−23.21***
Global warming, Terrestrial ecosystem	Pt	2.09×10^{-2}	2.72×10^{-2}	-0.63×10^{-2}	**−23.20**
Global warming, Freshwater ecosystem	Pt	5.71×10^{-7}	7.44×10^{-7}	-1.73×10^{-7}	**−23.20**
Stratospheric ozone depletion	Pt	6.03×10^{-4}	7.87×10^{-4}	-1.84×10^{-4}	**−23.40**
Ionizing radiation	Pt	7.74×10^{-5}	4.15×10^{-5}	3.59×10^{-5}	**86.55**
Ozone formation, Human health	Pt	3.89×10^{-4}	5.23×10^{-4}	-1.34×10^{-4}	**−25.69**
Fine particulate matter formation	***Pt***	***1.77×10^{-1}***	***2.33×10^{-1}***	***-0.56×10^{-1}***	***−24.17***
Ozone formation, Terrestrial ecosystem	Pt	2.48×10^{-3}	3.34×10^{-3}	-0.85×10^{-3}	**−25.55**
Terrestrial acidification	Pt	9.79×10^{-3}	14.19×10^{-3}	-4.40×10^{-3}	**−31.04**
Freshwater eutrophication	Pt	1.67×10^{-3}	1.75×10^{-3}	-0.08×10^{-3}	**−4.70**
Marine eutrophication	Pt	1.66×10^{-5}	1.97×10^{-5}	-0.32×10^{-5}	**−15.95**
Terrestrial ecotoxicity	Pt	3.10×10^{-4}	3.03×10^{-4}	0.07×10^{-4}	**2.24**
Freshwater ecotoxicity	Pt	2.91×10^{-4}	3.00×10^{-4}	-0.09×10^{-4}	**−2.90**
Marine ecotoxicity	Pt	4.95×10^{-5}	4.90×10^{-5}	0.05×10^{-5}	**0.98**
Human carcinogenic toxicity	Pt	1.72×10^{-2}	1.79×10^{-2}	-0.07×10^{-2}	**−3.74**
Human non-carcinogenic toxicity	***Pt***	***1.15×10^{-1}***	***4.09×10^{-1}***	***-2.94×10^{-1}***	***−71.95***
Land use	***Pt***	***0.76×10^{-1}***	***1.49×10^{-1}***	***-0.73×10^{-1}***	***−48.78***
Mineral resource scarcity	Pt	1.76×10^{-4}	1.87×10^{-4}	-0.11×10^{-4}	**−6.03**
Fossil resource scarcity	Pt	8.88×10^{-3}	9.38×10^{-3}	-0.50×10^{-3}	**−5.32**
Water consumption, Human health	Pt	2.33×10^{-2}	2.26×10^{-2}	0.07×10^{-2}	**3.13**
Water consumption, Terrestrial ecosystem	Pt	6.58×10^{-3}	6.23×10^{-3}	0.35×10^{-3}	**5.55**
Water consumption, Aquatic ecosystem	Pt	2.33×10^{-6}	2.17×10^{-6}	0.16×10^{-6}	**7.16**
Damage Category					
Human health	Pt	4.90×10^{-1}	8.88×10^{-1}	-3.98×10^{-1}	**−44.83**
Ecosystems	Pt	1.18×10^{-1}	2.02×10^{-1}	-0.84×10^{-1}	**−41.50**
Resources	Pt	9.06×10^{-3}	9.57×10^{-3}	-0.51×10^{-3}	**−5.34**
Total	Pt	6.17×10^{-1}	11.00×10^{-1}	-4.83×10^{-1}	**−43.88**

Note: Impact categories with the highest importance are in Bold Italics.

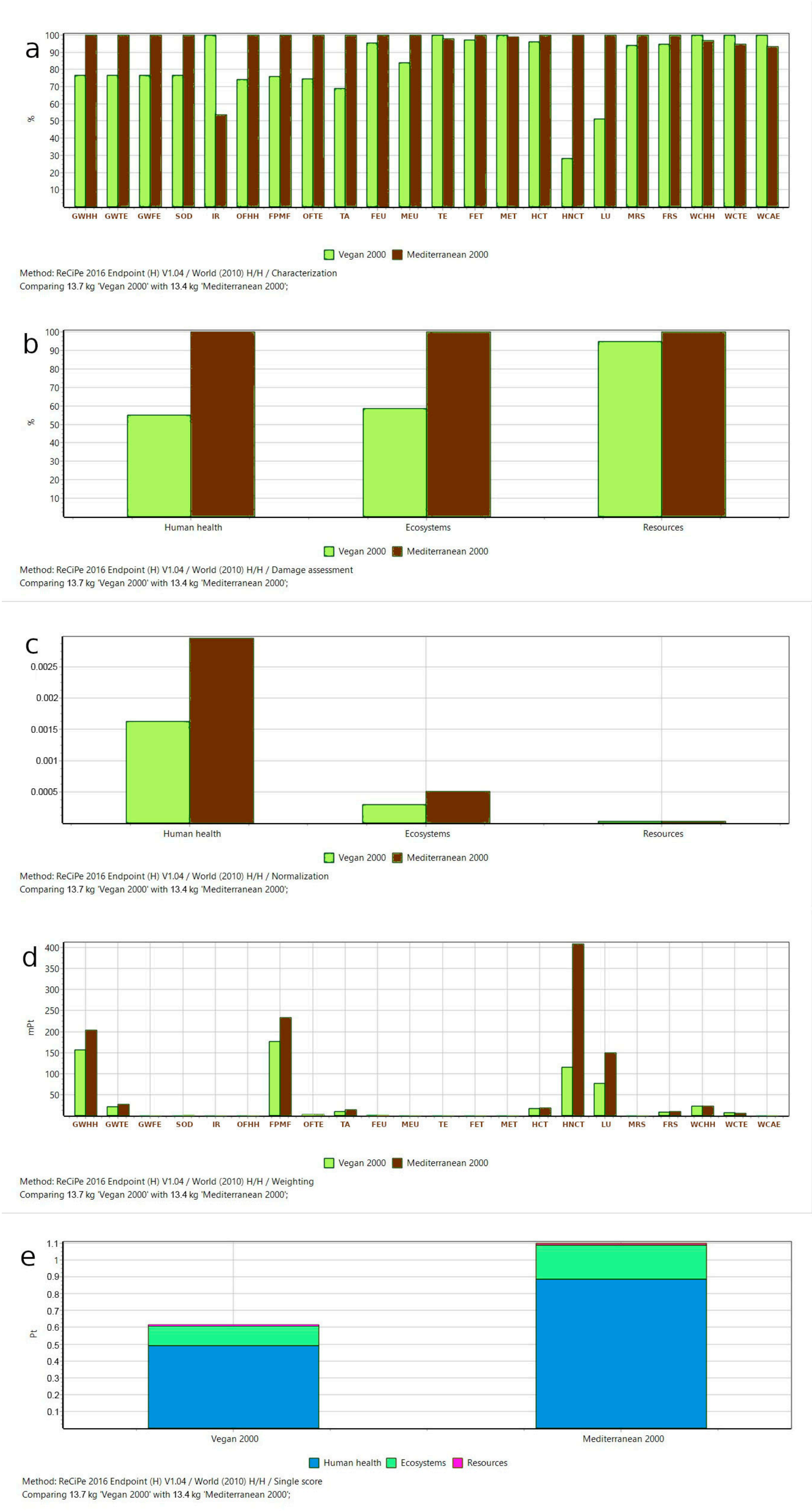

Figure 2. Comparison between Vegan diet and Mediterranean diet (2000 kcal): (**a**) Characterization; (**b**) Damage Assessment; (**c**) Normalization; (**d**) Weighting; (**e**) Aggregated Weighted Average (Single

Score). GWHH: Global warming, Human health; GWTE: Global warming, Terrestrial ecosystems; GWFE: Global warming, Freshwater ecosystems; SOD: Stratospheric ozone depletion; IR: Ionizing radiation; OFHH: Ozone formation, Human health; FPMF: Fine particulate matter formation; OFTE: Ozone formation, Terrestrial ecosystems; TA: Terrestrial acidification; FEU: Freshwater eutrophication; MEU: Marine eutrophication; TE: Terrestrial ecotoxicity; FET: Freshwater ecotoxicity; MET: Marine ecotoxicity; HCT: Human carcinogenic toxicity; HNCT: Human non-carcinogenic toxicity; LU: Land use; MRS: Mineral resource scarcity; FRS: Fossil resource scarcity; WCHH: Water consumption, Human health; WCTE: Water consumption, Terrestrial ecosystem; WCAE: Water consumption, Aquatic ecosystems.

To make easier the comparison of the values, we used the same order of magnitude for each category (same row) in the tables.

In Figure 2, the colors indicate the contribution of the two diets: light green for the Vegan diet, and brown for the Mediterranean diet.

3.1. Characterization

Table 2a and Figure 2a provide a closer look at the contributions of the two diets to various categories of Impact (midpoint characterization factors).

In this step, all substances are multiplied by characterization factors (CF), which quantifies how much impact a single unit of a product has in the various categories of environmental impact. In Figure 2a, all impact scores are displayed on a 100% scale.

3.2. Damage Assessment

This step (endpoints) aggregates a number of impact category indicators into a Damage category. At this stage of the calculation (Table 2b, Figure 2b), the difference in the impact of the two diets for the three Damage categories is evident: the Vegan diet scores almost half of the impact of the Mediterranean diet with respect to the human health and the ecosystems endpoints. Also, in Figure 2b, all impact scores are displayed on a 100% scale.

3.3. Normalization

In this step (Table 2c, Figure 2c), the impact is compared to a reference value, termed "normalization reference". It is a major factor in the aggregation process and facilitates comparisons, comprehension, communication, and decision-making. The results of this step confirm the effects on ecosystems and human health of the previous phase.

3.4. Weighted Average to Obtain a Single Score

Weighting results are reported in Figure 2d,e, and Table 3.

Despite the small difference in the amount of animal products (10.6% of the total calories), the Vegan diet's overall impact (Single Score) is 43.88% lower than the Mediterranean diet's impact.

Table 3 also provides the detailed values of the Impact categories' Points, which quantify the contributions of the two diets to the categories of Impact (midpoint characterization factors): the higher the value, the higher the impact. The effects of the various Impact categories will be commented on in Section 4, the Discussion.

The differences between the two diets are also expressed in percentages (Table 3, last column).

For a better understanding of the single contribution of each food group (Process Contribution), we propose some details of their impact, calculated with the Single Score ReCiPe 2016 Endpoint H method [16]. Data are presented in Appendix A.

The impact of the two diets on CO_2-equivalent emission has also been calculated by using the evaluation method developed by the Intergovernmental Panel on Climate Change (IPCC), available on SimaPro®, and is shown in Appendix B.

In Appendix C, we propose two examples of comparison between animal and analogous protein plant foods.

4. Discussion

In addition to human health, over the last few years, researchers have begun investigating dietary strategies as a means of reducing environmental impacts due to the food system. For instance, the food system was estimated to contribute between 19% and 29% of global greenhouse gas (GHG) emissions and to account for approximately 70% of freshwater use globally [6,9,17].

In order to achieve sustainable diets, which must also be healthy, a public strategy should focus on improving energy balance and dietary changes toward predominantly plant-based diets that are consistent with healthy eating guidelines [18].

Reducing our reliance on animal foods is widely acknowledged as one of the most effective ways—on the individual level—to reduce our environmental impact on climate change, i.e., GHG production, and on other aspects like land use, pollutant emissions etc. [17,19–21].

The food system represents the primary driver of land use [22]: the land is tightly interrelated with climate change and, consequently, GHG emissions. Methane and nitrous oxide, which are potent GHGs produced by livestock, are short-lived if compared to CO_2 itself. A phaseout of livestock production, and the consequent land restoration, even in the absence of any other emission reductions, would translate into a first rapid reduction of GHGs, due to the decay of the two gases [23].

We have previously used LCA methodology to compare the environmental impact of Lacto-ovo-vegetarian, Vegan and Omnivorous balanced diets, showing that the lower the animal food contribution of the diet, the lower the impact was [10,11,24].

To our knowledge, no study has so far compared the total environmental impact of the Mediterranean diet with that of the Vegan diet. The available studies either did not compare the two diets contextually or compared only some of the impacts but not the total impact [25–35].

The original Mediterranean diet is a balanced diet meeting nutritional recommendations. It is based mainly on plant foods, seasonal and locally available, whose consumption goes hand in hand with their production and the social and cultural factors that make this diet so typical, to the point of being recognized as an "Intangible Cultural Heritage of Humanity" [36,37].

However, many factors, among which mainly globalization and the advent of modern food production techniques, with the change of traditional habits, are leading to a progressive reduction of the population's adherence to the Mediterranean diet [38].

Although the Mediterranean diet is still considered culturally acceptable, cheap, and healthy [39,40], the Vegan diet is becoming utmost popular.

Foods composing a Vegan diet are very similar to those of the Mediterranean tradition. A well-planned Vegan diet is considered nutritionally adequate and healthy [41], and in a study that compared the cost of different diets, the results presented the Vegan diet to be the cheaper one [25].

The 2015 (Updated in 2021) Dietary Guidelines Scientific Advisory Committee states that "*a dietary pattern that is higher in plant-based foods, such as vegetables, fruits, whole grains, legumes, nuts, and seeds, and lower in animal-based foods is more health promoting and associated with less environmental impact (GHGE and energy, land, and water use) than the current average US diet*" [42].

So, what can be the difference in the total environmental impact of two similar plant-based diets, which respectively greatly limit or eliminate animal foods?

Although the two diets are very similar from a nutritional point of view, the analysis of their respective environmental impact has highlighted important differences, which we discuss below.

Our comparison of the Impact categories of the Mediterranean vs. Vegan diet showed many differences favoring the Vegan one: Human non-carcinogenic toxicity (−71.95%), Land use (−48.78%), Terrestrial acidification (−31.04%), Ozone formation (mean −25.62%), Stratospheric ozone depletion (−23.40%), Fine particulate formation (−24.17%), Global warming (mean −23.2%). Lesser differences favoring the Vegan diet were present for Freshwater eutrophication and ecotoxicity, Human carcinogenic toxicity, Mineral resource scarcity and Fossil resource scarcity (mean −4.54% [from −6.03% to −2.9%]).

The remaining Impact categories were instead in favor of the Mediterranean diet, but except for Ionizing radiation (86.55%), the other ones elicited low differences: Terrestrial and marine ecotoxicity (2.24% and 0.98%, respectively, mean 1.61%) and Water consumption (mean 5.28% [from 3.13% to 7.16%]).

However, a more careful analysis of Table 3 and Figure 2d highlighted that in terms of absolute values, the Impact categories with the highest importance are 4 (the ones highlighted in Bold Italics font): GWHH: Global warming, Human health; FPMF: Fine particulate matter formation; HNCT: Human non-carcinogenic toxicity; LU: Land use. Their contribution to the total impact appeared preponderant compared to the other Impact categories, and the differences between the two diets were always in favor of the Vegan diet.

Moreover, once the Impact categories were aggregated by Damage categories, the Vegan diet was favored for all Damage categories, and its total impact was lower than the Mediterranean diet. LCA calculations (with ReCiPe 2016 Endpoint H [16]) showed that, despite a low difference in the protein foods (representing 10.6% of total kcalories), the total environmental impact of the Vegan diet was 43.88% lower than the Mediterranean diet's impact, which means that the Mediterranean diet's impact was 78.18% higher than the Vegan diet's impact.

This finding confirms the validity of applying the LCA analysis to all the Impact categories to obtain an assessment more in line with real life: a single or few Impact categories may not reflect the entity of the Damage categories and of the total environmental impact of the diet or could even reverse the conclusions.

Our calculations showed that the 10.6% of calories derived from animal products were responsible for about half (47%) of the global impact of the Mediterranean diet, with meat showing the largest contribution (around 30%), despite the minimum amount included (60 g/week). See Appendix A for details.

Regarding protein sources, in our calculations, legumes and seitan had, respectively, a total impact at the Single Score level of about 84% and 32% lower than mixed meat, and soy milk's total impact was 79% lower than cow's milk's one (data are shown in Appendix C).

Considering the climate emergency, we also launched an LCA calculation based on IPCC 2013 GWP (100a) method, available in SimaPro®, to test the environmental effect of the two plant-based diets on GHG emission. According to our results, the Vegan diet impact was 78.7% of that of the Mediterranean diet (Appendix B, Figure A4).

There is enough evidence that plant-based diets are both adequate and protective against the most widespread chronic diseases in the developed world [41]. However, food systems should also be economically viable and improve food security, prevent malnutrition and reduce environmental degradation [5,43].

Thanks to LCA analysis, we highlighted how, among the various impact categories especially affected by the two diets, one consistently emerged: animal-derived foods represent a significant burden for the Earth's soil. Soil scarcity is an insufficiently discussed emergency, given that the Earth's surface is still free from human activities represents a fundamental factor for our survival and for ecological balance. Land scarcity also threatens local food security and biodiversity. In this scenario, the food system is the primary driver of land use, and land scarcity is the primary driver of zoonotic spillovers [44].

Food systems need to deal with human health, national economy and culture, but also address climate change mitigation, tackle the depletion of natural resources, and possibly, not forget workers' human rights (equity and fair trade).

Although it is claimed that a diet with a moderate amount of animal foods has only a modestly higher impact on the environment, with respect to a plant-only diet, in our study, we demonstrated that even modest consumption of animal products had a consistent impact on critical environmental aspects.

According to these data, animal-based food production represents a significant burden for the planet. Given that the average diet is much higher in animal products than the Mediterranean diet we used for comparison, the consequences can be unpredictable.

Food policies should be planned by a multidisciplinary task force, which includes collaboration among scholars and stakeholders from multiple disciplines and sectors.

5. Limitations

The environmental impact of food production is region-specific, while we used global market standards. Therefore, there can be relevant differences in environmental impacts when referring to regional or local productions, depending on the origin, quality, distance from the consumption site, traditional processing, price etc. Thus, our findings cannot be directly transferred to a region-specific environmental impact system.

Data used for our calculations were derived from the Ecoinvent® database, which is continuously updated and offers detailed uncertainty characterizations for most energy and material flows in its lifecycle inventory data.

Worth noting when interpreting midpoints results: according to ISO 14044 [45], in LCA calculations, water consumption is not a direct expression of how much water is used in the process. In LCA, a product or service is evaluated for the water impact throughout its entire life cycle, but only the "blue water" is counted. Green water is not considered in LCA, while grey water is partly assessed in a few impact categories. On the other hand, "water footprint" evaluates water based on volumetric use, and this method quantifies and maps green, blue and grey water [46]. There's an ongoing and heated debate about whether the water footprint should be a volumetric or an impact-based indicator [47]. So, compared to other impact categories, our water consumption results are especially uncertain since the amount of water is strictly linked to local conditions such as rainfall, irrigation, evapotranspiration and pedoclimatic elements [48].

In simple terms, sustainable diets are context specific. Important factors like the local climate, the physical properties of soil and land, water availability, and many others, including the diversity of agricultural production systems and local environmental settings, as well as local culture, should be taken into consideration in the decision-making process of sustainable diets and sustainable food systems.

Nevertheless, despite the uncertainty and variability inherent in these complicated systems, this simple underlying trend provides relatively high confidence in the direction of the conclusions.

6. Conclusions

Diet has an impact on both health and the ecosystem. In our work, we have compared two sustainable diets with very similar nutrient compositions but with substantial differences in their total environmental impacts. The replacement of a small calorie quota (10.6%) represented by animal foods with plant foods showed significant improvement in the total environmental impact, especially for ecosystems and human health.

This suggests that the more plant-based the diet is, the less it will impact the environment. This information is noteworthy in light of how many countries show a diet rich in animal foods and how much this represents a global risk to sustainability.

However, while the health consequences are already known, there is still little attention on the environmental outcomes, given how even small amounts of animal food can make a difference.

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Appendix A. Process Contribution

LCA analysis allows for the identification of critical issues, their sources, how they interact with environmental factors, and their consequences.

In SimaPro®, the "process tree" provides an overview of relevant issues. "Weighted contribution" analysis has a similar function. The latter calculates the relative contribution of each process set in a list of processes.

Since one of the objectives of this study was to gain a deeper understanding of the crucial factors underlying the differences between the two plant-based diets, we decided to run a process contribution analysis.

The following details provide an overview of the differences in the impact of the two plant-based diets, based on the weight contributions of each food group, calculated with the Single Score ReCiPe 2016 Endpoint H method [16] (Table A1).

Table A1. Comparison between the contributions of the single foods in the two one-week diets. Impacts are expressed as Single Score and represent their weighted values. Cut-off: 0.9% (Pt: Points).

Process	Project	Unit	Vegan	Mediterranean
Almond {GLO}∣ market for almond ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	0.0604	0.0575
Aubergine {GLO}∣ market for ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	0.0147	0.0147
Bell pepper {GLO}∣ market for bell pepper ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	0.0506	0.0506
Cashew {GLO}∣ market for cashew ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	0.0216	0.0205
Cheese, from cow milk, fresh, unripened {GLO}∣ cheese production, soft, from cow milk ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	x	0.0743
Chickpea {GLO}∣ market for chickpea ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	0.0107	0.0049
Cucumber {GLO}∣ market for ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	0.0253	0.0253
Electricity, low voltage {GLO}∣ market group for ∣ Cut-off, S—Copied from ecoinvent	World Food LCA Database	Pt	0.0205	0.0200
Fish, marine {GLO}∣ market for marine fish ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	x	0.0206
Gas stove	Diets' comparison	Pt	0.0217	0.0192
Green asparagus {GLO}∣ market for ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	0.0173	0.0173
Lentil, at farm/AU Economic	Agri-footprint—economic allocation	Pt	0.0107	0.0048
Lettuce {GLO}∣ market for ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	0.0272	0.0272
Natural gas, high pressure {IT}∣ market for ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	0.0111	0.0098
Peanut {GLO}∣ market for peanut ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	0.0162	0.0155
Red meat, live weight {GLO}∣ market for ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	x	0.3345
Rice, non-basmati {GLO}∣ market for rice, non-basmati ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	0.0151	0.0151
Skimmed milk, from cow milk {GLO}∣ market for ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	x	0.0844
Sodium chloride, powder {RER}∣ production ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	0.0175	0.0004
Wastewater, unpolluted {CH}∣ treatment of, capacity 5E9l/year ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	0.0249	0.0249
Wheat grain {RoW}∣ wheat production ∣ Cut-off, S	Ecoinvent 3 [a]	Pt	0.0874	0.0785
Remaining processes		Pt	0.1644	0.1799
All processes		Pt	0.6173	1.0998
Animal foods		Pt	0.0000	0.5138 (47%)

[a] allocation, cut-off by classification—system.

According to the above calculations, the 10.6% of calories derived from animal products are responsible for about half (47%) of the global impact of the Mediterranean diet, with meat showing the largest contribution (around 30%), despite the minimum amount included (60 g/week) (Figures A1 and A2).

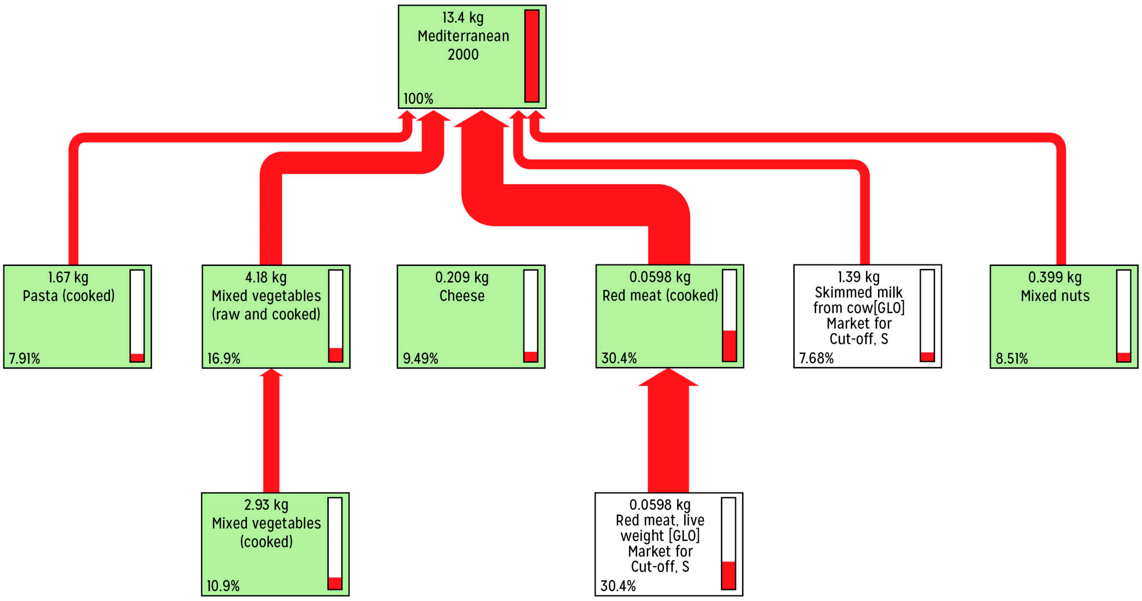

Figure A1. Mediterranean diet's process contribution (tree). Functional unit: 1 week of Mediterranean diet foods (13.4 kg). Node cut-off: 7.5%, cumulative indicator as a percentage.

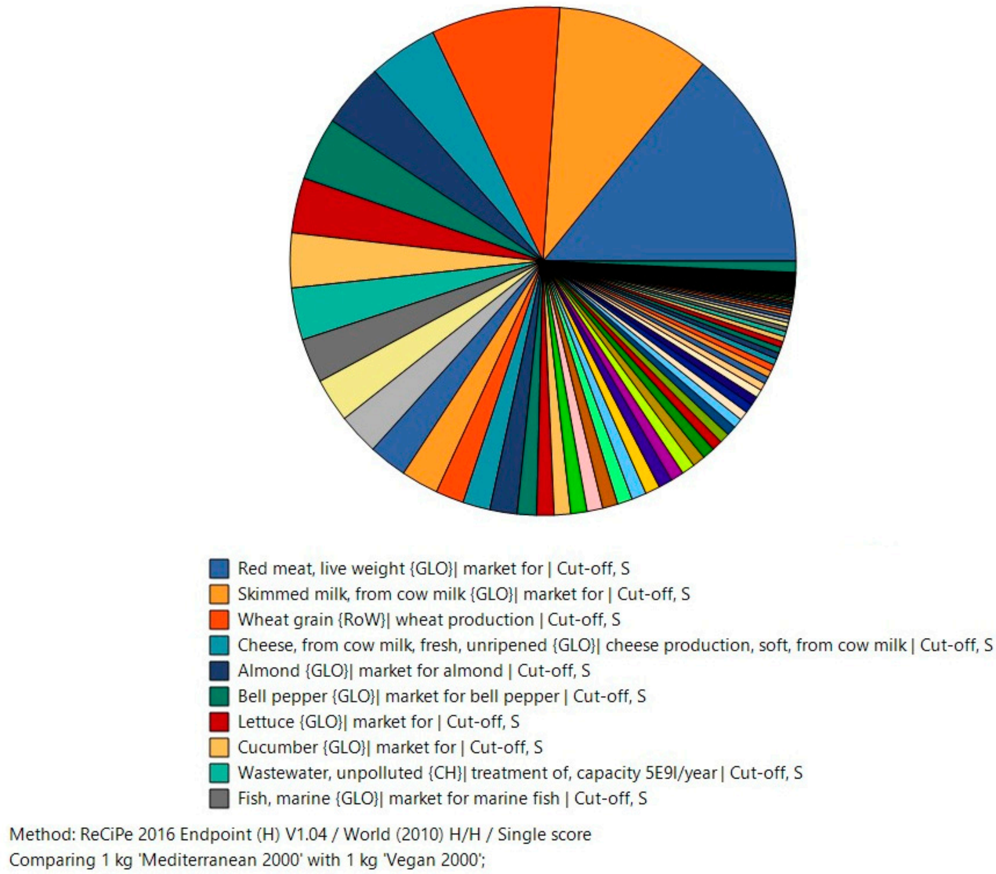

Figure A2. Mediterranean diet's process contribution (cake). The contribution of each food group is calculated on a 100% scale (cut off 0.1%).

The impact for each category needs to be related to the quantity of the corresponding food group (Table A2).

Table A2. Comparison of the relative impact of the Vegan and Mediterranean diets' food groups.

Food Group	Quantity (kg), Pts and %					
	Vegan Diet			Mediterranean Diet		
	Quantity	Pts	%	Quantity	Pts	%
Mixed cooked cereals	1.12	0.021	3.34	1.12	0.021	1.88
Cooked rice	0.72	0.019	3.14	0.72	0.019	1.76
Spaghetti	1.68	0.087	14.2	1.68	0.087	7.91
Bread	0.66	0.046	7.55	0.66	0.046	4.24
Olive oil	0.08	0.007	1.20	0.14	0.013	1.18
Mixed cooked legumes	0.88	0.043	6.95	0.40	0.019	1.77
Mixed fruit	2.63	0.046	7.47	2.10	0.037	3.35
Mixed cooked vegetables	4.20	0.186	30.00	4.20	0.186	16.9
Nuts	0.42	0.098	15.9	0.40	0.093	8.51
Sunflower oil	0.06	0.010	1.57	x		
Soy dessert	0.25	0.007	1.17	x		
Soy drink	0.80	0.011	1.82	x		
Seitan	0.06	0.029	4.70	x		
Tofu	0.16	0.007	10.5	x		
Cheese	x			0.21	0.104	9.49
Cooked fish	x			0.12	0.021	1.89
Cooked red meat	x			0.06	0.333	30.04
Skimmed milk	x			1.40	0.084	7.68
Cooked chicken	x			0.12	0.014	1.27
Cooked egg	x			0.12	0.200	1.80

For example, vegetables seem to have the highest impact in the Vegan diet (30%) and a consistent contribution to the Mediterranean environmental footprint (16.9%), but this is due to their higher quantity (4.2 kg/week in both diets) (Figures A2 and A3).

With only 209 g/week, cheese also proves to be a considerable environmental burden, contributing 0.104 Pts (9.5%) to the total Mediterranean diet impact. When meat and cheese are considered together, they are responsible for over 40% of their weighted environmental impact (Single Score), even though they make up only 0.27/13.4 kg (2%) of the total food's weight.

In the Vegan diet, mixed nuts, and in particular, almonds, show the overall highest contribution/weight to its environmental footprint: respectively almost 16% and 10% on a 100% scale (Figure A3).

On the contrary, in the Mediterranean diet, mixed nuts, compared to red meat, contribute less: 8.5% versus 30% (Figure A1).

Despite the relatively high environmental impact shown by nuts, their consumption is naturally limited by their own characteristics, their average cost, and their calorie content. Nuts (including peanuts, despite being legumes) provide healthy fats and protective phytocomplexes and are generally consumed below desirable amounts in Europe.

Considering these facts, we believe that the public should become aware of the environmental impacts of various foods, but we deem that nuts do not fit the profile of foods to be restricted or avoided for environmental reasons. The sustainability of a diet must also consider the nutritional profile of foods and their impact on human health.

The process tree and the process contribution clearly show that the factors underlying the differences in the environmental impacts of the two diets reside in the 10.6% of dietary calories as animal food products, especially red meats.

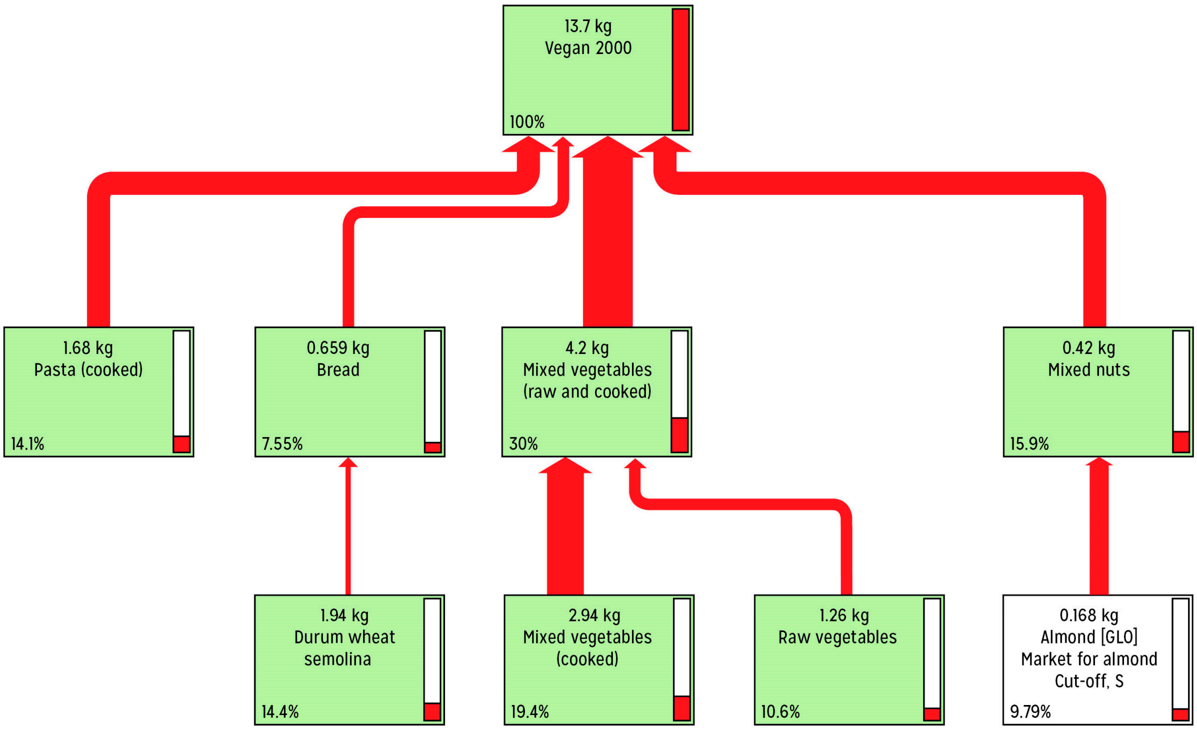

Figure A3. Vegan diet's process contribution (tree). Functional unit: 1 week of Mediterranean diet foods (13.7 kg). Node cut-off: 7.5%, cumulative indicator as a percentage.

Appendix B. Single Issues: Comparison of the Two Diets by the IPCC 2013

In order to resolve the climate crisis, transportation and energy production must reduce their GHG emissions massively. The measures adopted so far to curb global warming have ultimately proved insufficient and ineffective since, despite continuing reductions in emissions, they have increased over time. To limit global warming to 1.5 °C by 2050, also food-related emissions will likely need to be significantly reduced, even if emissions from other sources are drastically cut.

In fact, according to estimates, a global shift to a plant-based diet would considerably lower GHG emissions more than increasing agricultural efficiency, cutting food waste, limiting excess consumption, increasing yields, and reducing livestock emissions [23,49].

Because of the climate emergency declaration issued by many government institutions, we decided to include the GHG emissions issue in this Appendix B, using the evaluation method developed by the Intergovernmental Panel on Climate Change (IPCC).

IPCC is "*the international body for assessing the science related to climate change*". The IPCC was set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Program (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts, and future risks, as well as options for adaptation and mitigation.

GHG is expressed as carbon dioxide equivalents (CO_2-eq), a composite indicator that generally reflects the total impact of carbon dioxide, methane, and nitrous oxide.

IPCC calculation is based on a 100% scale. According to this method, the Vegan diet is confirmed to elicit a lower environmental impact: the Vegan diet allows for a 21% reduction in GHG emissions (Table A3 and Figure A4).

Table A3. Comparison of the two diets' impact according to IPCC 2013.

Impact Category	Unit	Vegan Diet	Mediterranean Diet	Δ Veg-Med	%
IPCC GWP 100a	Kg CO_2-eq	12.9	16.4	−3.5	**−21.34**

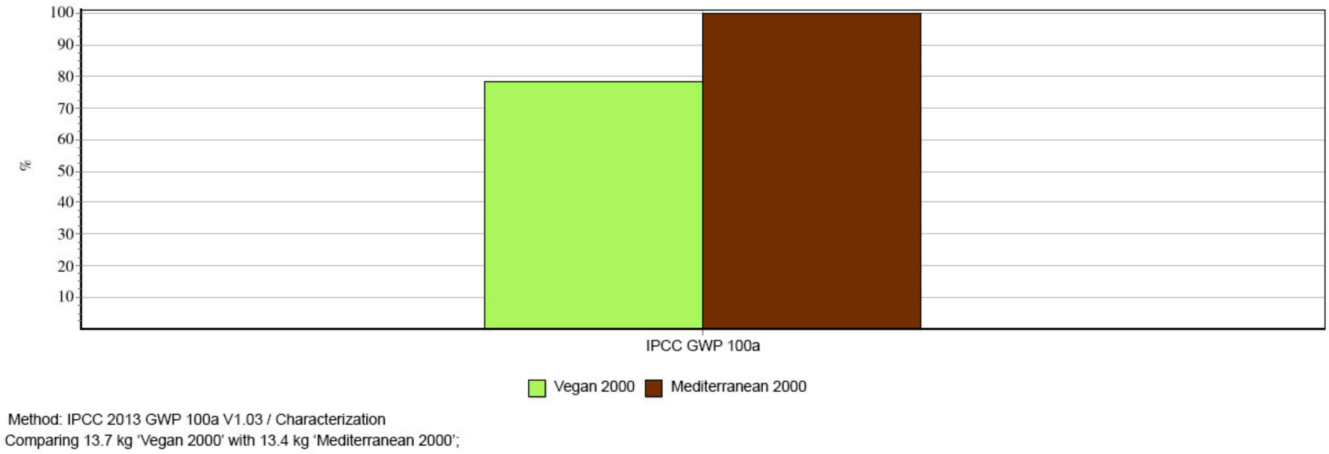

Figure A4. Comparison of the two diets' impact according to IPCC 2013 (available from SimaPro®).

It must be considered, nevertheless, that this evaluation method of analysis doesn't include soil restoration: hence, these differences could be underestimated by the return of land currently used in livestock production to its native state [23].

Appendix C. Calculation of Protein Plant Foods vs. Protein Animal Foods: Two Examples

To provide a better insight into the impact of the food categories, we compared two protein animal foods with two corresponding plant protein foods, similar in their nutritional profile.

Calculations were performed with ReCiPe 2016, Endpoint H [16].

Appendix C.1. Comparison between Soy Milk and Cow Milk

First, we compared 1 Kg of Soy Milk with the same amount of Cow Milk. According to the table and figure below, soy milk shows only 21% of the total impact (Single Score) of cow milk, which means that the total impact of soy milk is 79% lower than the total impact of cow milk (Table A4 and Figure A5).

Table A4. Life Cycle Assessment Calculation (LCIA): comparison between Soy Milk and Cow Milk. Impact Categories and Damage Categories. Aggregated Weighted Average: total environmental load expressed as a Single Score (mPt = milliPoints).

Aggregated Weighted Average (Single Score)					
Impact Category	**Unit**	**Soy Milk**	**Cow Milk**	**Δ Soy-Cow**	**%**
Global warming, Human health	mPt	3.7999	23.9929	−20.1930	−84.16
Global warming, Terrestrial ecosystems	mPt	0.5068	3.1975	−2.6907	−84.15
Global warming, Freshwater ecosystems	mPt	1.38×10^{-5}	8.73×10^{-5}	-7.35×10^{-5}	−84.15
Stratospheric ozone depletion	mPt	1.32×10^{-2}	5.51×10^{-2}	-4.20×10^{-2}	−76.13
Ionizing radiation	mPt	0.98×10^{-3}	4.57×10^{-3}	-3.59×10^{-3}	−78.46
Ozone formation, Human health	mPt	1.41×10^{-2}	8.61×10^{-2}	-7.20×10^{-2}	−83.63
Fine particulate matter formation	mPt	3.8525	20.0071	−16.2182	−80.81
Ozone formation, Terrestrial ecosystems	mPt	0.90×10^{-1}	5.44×10^{-1}	-4.54×10^{-1}	−83.43
Terrestrial acidification	mPt	0.1635	1.3701	−1.2066	−88.07
Freshwater eutrophication	mPt	2.64×10^{-2}	8.00×10^{-2}	-5.36×10^{-2}	−67.02
Marine eutrophication	mPt	5.67×10^{-4}	9.10×10^{-4}	-3.43×10^{-4}	−37.66
Terrestrial ecotoxicity	mPt	1.24×10^{-2}	1.39×10^{-2}	-0.15×10^{-2}	−10.81
Freshwater ecotoxicity	mPt	4.05×10^{-3}	8.62×10^{-3}	-4.57×10^{-3}	−53.03
Marine ecotoxicity	mPt	8.58×10^{-4}	14.38×10^{-4}	-5.80×10^{-4}	−40.33
Human carcinogenic toxicity	mPt	3.32×10^{-1}	7.75×10^{-1}	-4.43×10^{-1}	−57.13
Human non-carcinogenic toxicity	mPt	0.8328	1.9615	−1.1288	−57.55

Table A4. *Cont.*

Aggregated Weighted Average (Single Score)					
Impact Category	**Unit**	**Soy Milk**	**Cow Milk**	**Δ Soy-Cow**	**%**
Land use	mPt	2.6577	7.5275	−4.8698	−64.69
Mineral resource scarcity	mPt	0.23×10^{-2}	2.42×10^{-2}	-2.19×10^{-2}	−90.65
Fossil resource scarcity	mPt	3.48×10^{-1}	4.36×10^{-1}	-0.88×10^{-1}	−20.19
Water consumption, Human health	mPt	-0.25×10^{-1}	2.37×10^{-1}	-2.62×10^{-1}	−110.41
Water consumption, Terrestrial ecosystem	mPt	1.10×10^{-2}	6.98×10^{-2}	-5.88×10^{-2}	−84.26
Water consumption, Aquatic ecosystems	mPt	1.30×10^{-5}	1.26×10^{-5}	0.04×10^{-5}	3.01
Damage category					
Human health	mPt	8.8210	47.1832	−38.3622	−81.30
Ecosystems	mPt	3.4732	12.8134	−9.3402	−72.89
Resources	mPt	0.3500	0.4599	−0.1099	−23.90
Total	mPt	12.6442	60.4566	−47.8124	−79.09

Figure A5. Comparison between Soy Milk and Cow Milk: (**a**) Characterization; (**b**) Damage Assessment; (**c**) Normalization; (**d**) Aggregated Weighted Average (Single Score). GWHH: Global warming, Human health; GWTE: Global warming, Terrestrial ecosystems; GWFE: Global warming, Freshwater ecosystems; SOD: Stratospheric ozone depletion; IR: Ionizing radiation; OFHH: Ozone formation, Human health; FPMF: Fine particulate matter formation; OFTE: Ozone formation, Terrestrial ecosystems; TA: Terrestrial acidification; FEU: Freshwater eutrophication; MEU: Marine eutrophication; TE: Terrestrial ecotoxicity; FET: Freshwater ecotoxicity; MET: Marine ecotoxicity; HCT: Human carcinogenic toxicity; HNCT: Human non-carcinogenic toxicity; LU: Land use; MRS: Mineral resource scarcity; FRS: Fossil resource scarcity; WCHH: Water consumption, Human health; WCTE: Water consumption, Terrestrial ecosystem; WCAE: Water consumption, Aquatic ecosystems.

Appendix C.2. Comparison among Cooked Mixed Meat, Seitan, and Mixed Legumes

The difference in the impact of the two sources of proteins (animal vs. plant) was also investigated. According to the table and figure below, mixed legumes and seitan have, respectively, an impact that is 84% and 32% lower than mixed meat.

The results are presented in Table A5 and Figure A6.

Table A5. Life Cycle Assessment Calculation (LCIA): comparison among Mixed Meat (cooked), Seitan and Mixed Legumes (cooked), proposed for steps. Impact Categories and Damage Categories. Aggregated Weighted Average: total environmental load expressed as a Single Score (mPt = milliPoints).

Impact Category	Unit	Mixed Meat (Cooked)	Seitan	Mixed Legumes (Cooked)	Δ Seitan-Meat	Δ Legumes-Meat	% Seitan-Meat	% Legumes-Meat
Global warming, Human health	mPt	2.68×10^{2}	1.13×10^{2}	0.41×10^{2}	-1.54×10^{2}	-2.27×10^{2}	−57.62	−84.67
Global warming, Terrestrial ecosystems	mPt	3.57×10^{1}	1.51×10^{1}	0.55×10^{1}	-2.05×10^{1}	-3.02×10^{1}	−57.58	−84.65
Global warming, Freshwater ecosystems	mPt	9.75×10^{-4}	4.13×10^{-4}	1.50×10^{-4}	-5.61×10^{-4}	-8.25×10^{-4}	−57.58	−84.65
Stratospheric ozone depletion	mPt	9.21×10^{-1}	3.53×10^{-1}	0.67×10^{-1}	-5.68×10^{-1}	-8.53×10^{-1}	−61.67	−92.69
Ionizing radiation	mPt	4.53×10^{-2}	16.9×10^{-2}	0.15×10^{-2}	12.41×10^{-2}	-4.39×10^{-2}	273.81	−96.74
Ozone formation, Human health	mPt	9.00×10^{-1}	2.54×10^{-1}	0.33×10^{-1}	-6.46×10^{-1}	-8.67×10^{-1}	−71.77	−96.35
Fine particulate matter formation	mPt	2.48×10^{2}	1.45×10^{2}	0.17×10^{2}	-1.03×10^{2}	-2.31×10^{2}	−41.56	−93.12
Ozone formation, Terrestrial ecosystems	mPt	5.6807	1.6191	0.2102	−4.0615	−5.4704	−71.50	−96.30
Terrestrial acidification	mPt	18.3136	6.6124	1.2052	−11.7012	−17.1084	−63.89	−93.42
Freshwater eutrophication	mPt	1.1521	2.8497	0.0820	1.6976	−1.0701	147.35	−92.88
Marine eutrophication	mPt	2.14×10^{-2}	0.65×10^{-2}	0.27×10^{-2}	-1.49×10^{-2}	-1.87×10^{-2}	−69.77	−87.53
Terrestrial ecotoxicity	mPt	1.51×10^{-1}	6.41×10^{-1}	0.41×10^{-1}	4.89×10^{-1}	-1.10×10^{-1}	323.22	−72.81
Freshwater ecotoxicity	mPt	1.03×10^{-1}	7.28×10^{-1}	0.20×10^{-1}	6.25×10^{-1}	-0.83×10^{-1}	604.28	−80.54
Marine ecotoxicity	mPt	2.09×10^{-2}	14.11×10^{-2}	0.33×10^{-2}	12.01×10^{-2}	-1.76×10^{-2}	573.69	−84.28
Human carcinogenic toxicity	mPt	9.9775	27.6797	0.5171	17.7022	−9.4604	177.42	−94.82
Human non-carcinogenic toxicity	mPt	2.49×10^{1}	8.56×10^{1}	1.83×10^{1}	6.07×10^{1}	-0.66×10^{1}	243.31	−26.45
Land use	mPt	9.16×10^{1}	5.24×10^{1}	2.26×10^{1}	-3.92×10^{1}	-6.90×10^{1}	−42.74	−75.28
Mineral resource scarcity	mPt	2.93×10^{-1}	3.20×10^{-1}	0.06×10^{-1}	0.27×10^{-1}	-2.87×10^{-1}	9.26	−97.99
Fossil resource scarcity	mPt	5.5237	6.4076	2.4128	0.8839	−3.1109	16.00	−56.32
Water consumption, Human health	mPt	2.7328	0.1934	2.2419	0.1661	−0.4909	607.75	−17.96
Water consumption, Terrestrial ecosystem	mPt	9.06×10^{-1}	53.93×10^{-1}	6.97×10^{-1}	44.86×10^{-1}	-2.10×10^{-1}	494.96	−23.13
Water consumption, Aquatic ecosystems	mPt	1.46×10^{-4}	8.55×10^{-4}	2.95×10^{-4}	7.09×10^{-4}	1.49×10^{-4}	485.29	101.84
Damage Category								
Human health	mPt	5.55×10^{2}	3.92×10^{2}	0.79×10^{2}	-1.63×10^{2}	-4.76×10^{2}	−29.42	−85.71
Ecosystems	mPt	15.4×10^{1}	8.56×10^{1}	3.04×10^{1}	-6.81×10^{1}	-12.33×10^{1}	−44.30	−80.22
Resources	mPt	5.8167	6.7277	2.4187	0.0911	−3.3979	15.66	−58.42
Total	mPt	7.14×10^{2}	4.84×10^{2}	1.12×10^{2}	-2.30×10^{2}	-6.02×10^{2}	−32.26	−84.31

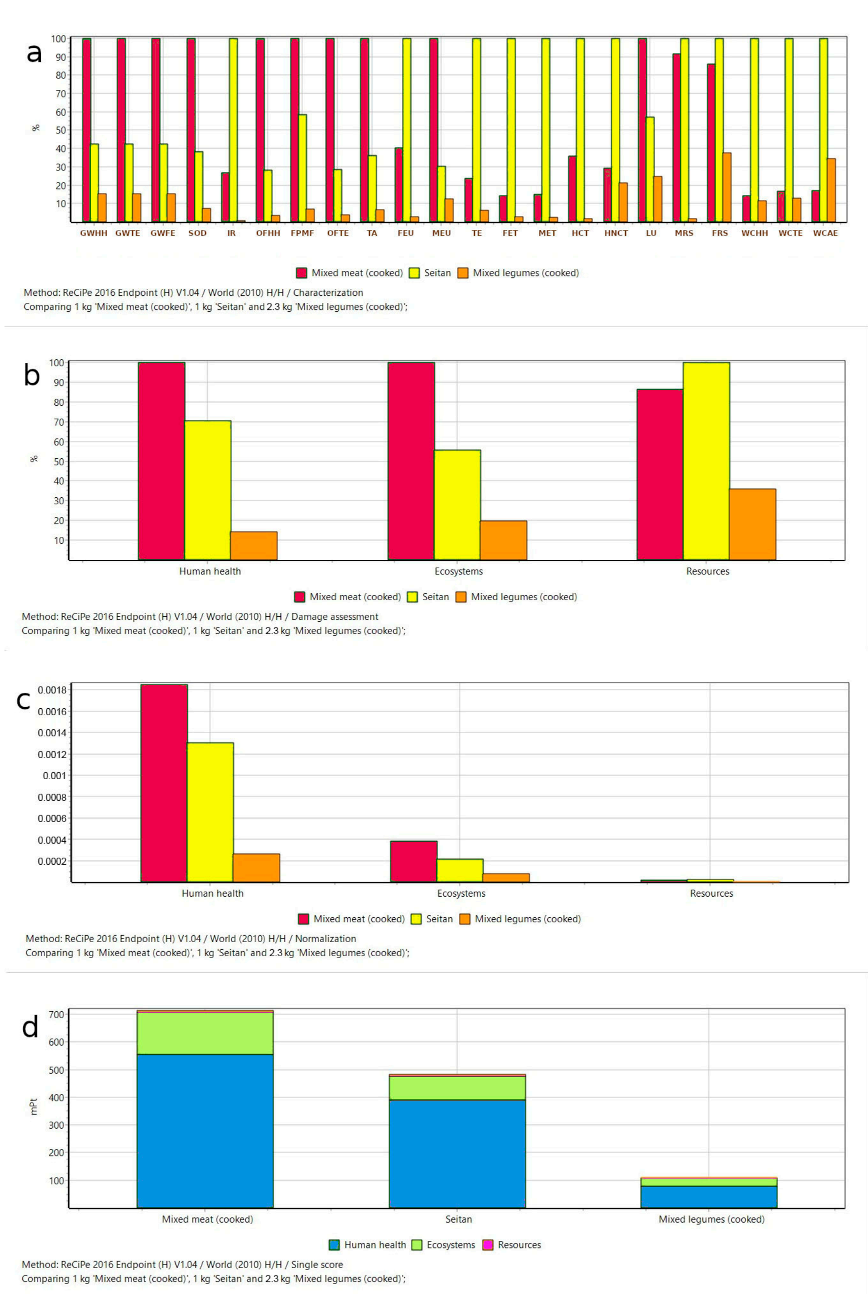

Figure A6. Comparison among Mixed Meat, Seitan and Mixed Legumes: (**a**) Characterization; (**b**) Damage Assessment; (**c**) Normalization; (**d**) Aggregated Weighted Average (Single Score). GWHH: Global warming, Human health; GWTE: Global warming, Terrestrial ecosystems; GWFE: Global warming, Freshwater ecosystems; SOD: Stratospheric ozone depletion; IR: Ionizing radiation; OFHH: Ozone formation, Human health; FPMF: Fine particulate matter formation; OFTE: Ozone formation, Terrestrial ecosystems; TA: Terrestrial acidification; FEU: Freshwater eutrophication; MEU: Marine eutrophication; TE: Terrestrial ecotoxicity; FET: Freshwater ecotoxicity; MET: Marine ecotoxicity; HCT: Human carcinogenic toxicity; HNCT: Human non-carcinogenic toxicity; LU: Land use; MRS: Mineral resource scarcity; FRS: Fossil resource scarcity; WCHH: Water consumption, Human health; WCTE: Water consumption, Terrestrial ecosystem; WCAE: Water consumption, Aquatic ecosystems.

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