Comparing Alternative Nutritional Functional Units for Expressing Life Cycle Greenhouse Gas Emissions in Food Production Systems

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ABSTRACT

Life cycle assessments (LCAs) of crop production systems and food products commonly report results using functional units of mass. While these functional units appear to facilitate comparison between different products, they fail to account for substantial differences in a multitude of benefits humans derive from food products, especially nutritional value. This study explores the effects of using different functional units, including mass, serving size, energy content, protein content and a composite nutrient score, on four food's life cycle global warming potential (GWP). Process-based LCA models of almonds, processed tomatoes (diced and paste), and rice, all produced in California, are used to calculate GWP. The results show that rice has the highest GWP except for the energy-content based functional unit, and almonds the lowest GWP except for the mass-based functional unit, and the performance of all the products are significantly affected by the choice of functional unit. The composite nutrient score functional unit appears to magnify the differences among the foods because it accentuates nutrient density, and thus foods like almonds perform better and foods like rice perform worse. Transparency in reporting and reporting multiple functional units is recommended for future studies.

Keywords: carbon footprint, nutrition, rice, almond, tomato

1. Introduction

Life cycle assessments (LCAs) of crop production systems and food products commonly report results using functional units (FUs) of mass of the harvested crop or food product. While these FUs appear to facilitate comparison between products, they fail to account for substantial differences in how various food products are actually used by consumers and the types of benefits consumers derive from these foods, especially nutritional value (Heller et al. 2013). Though meal- and diet-based FUs address this shortcoming (Carlsson-Kanyama 1998), they include functions beyond nutrition, such as those derived from culture. In many cases these additional functions improve the quality and interpretation of analysis and provide important context for decision-making; however, meal and diet-based LCAs may limit generalizability and comparability of results. This study explores a variety of FUs for diverse food products, including mass, serving size, energy content, protein, and a composite nutrient score, and examines the implications for how these products are perceived in terms of their greenhouse gas (GHG) footprints as calculated using LCA methods.

1.1. Previous work

The issue of FU selection in food LCAs has been the subject of discussion in diet-level assessments, meal-based assessments, comparison of organic and conventional production methods, and comparisons across food products or product categories, for example Camillis et al. (2012), Carlsson-Kanyama (1998), Davis and Sonneson (2008), Davis et al. (2010), Dutilh and Kramer (2000), Heller et al. (2013), Notarnicola et al. (2012), Saarinen (2012), and Van Kernebeek et al. (2013), to name but a few. The primary issue is selecting functional units that reflect both the goal of a study and the role of a particular food product in a diet.

While many comparative studies reject mass-based functional units, the European Food Sustainable Consumption and Production Round Table Working Group 1 recommends that business to consumer reporting use a functional unit of 100 g or ml (Camillis et al. 2012), illustrating the continued debate and ambiguity in the appropriate FU for food LCA studies. Complicating the issue of mass-based (or volume based) functional units and nutrition-based functional units is the fact that actual diets are not necessarily healthy, and may over-consume particular nutrients, complicating the selection of a FU when the role of a food or nutrient in a diet or meal is part of the functional unit. For example, Van Kerbeck et al. (2013) examined composite nutritional indices for use as FUs. They found that nutritional indices based on diets with and without protein intake caps arrived at different results. This and other studies highlight the challenge of developing FUs for food LCAs that are both based on scientifically relevant metrics of a food's value to the human diet, and reflect the real-world role of a food in the human diet.

Other issues that affect LCA-based food comparisons are those that are more universal to comparative LCAs and meta-analyses of LCAs, such as incommensurate system boundaries, differing key assumptions and a lack of transparency in reporting that prevents reinterpretation of results for new or alternate functional units.

1.2 Study Approach

This study compares three dissimilar foods produced and consumed in California; almonds, rice, and processed tomatoes. These foods were selected for three reasons: first, LCAs were conducted for these three products by the same research team leading to adequately similar system boundaries, data sources, and modeling approaches; second, because each food has significantly different roles in the human diet, they provided a good test bed for comparing different functional units; third, each of these foods is important globally due to the scale of production and their share of global or national production. California almond production constitutes 83% of global commercial production (USDA Office of Global Analysis 2013), California produces 96% of US processing tomatoes and is the single largest global producer (Economic Research Service 2012), and California is the second largest state in the US for rice production at approximately 2 million metric tons per year, 40% of which is exported to the international market (California Rice Commission 2014).

2. Methods

This study uses process-based LCA models of whole almonds (Kendall et al. 2012), processed tomatoes (Brodt et al. 2013), and rice, all produced in California. Because the rice LCA model was restricted GHG emissions, the only impact assessment category included in this study is GWP_{100} (Intergovernmental Panel on Climate Change 2007). Models were developed to cover all typical California production inputs, equipment operations, and yields on an annual basis, based on University of California Cost of Production studies and consultation with crop experts. Similar methods and system boundaries were used for all three products. In order to preclude confounding the results with different packaging options for different products, all results were calculated for the final products, to the food processing facility gate, without including any packaging. The almond study reports results for raw brown skin almonds. The processing tomato study evaluates two processed tomato products, canned tomato paste and canned diced tomatoes. The rice study reports a weighted average of white rice (90%) and brown rice (10%) based on their estimated production rates because these two products require different levels of milling.

The GWP results for these products are reported here in units of kg CO_2-equivalent per kg food product (kg CO_2e/kg):

- Whole almonds: 0.51 kg CO_2e/kg almond
- Tomato paste: 0.85 kg CO_2e/kg tomato paste
- Diced tomatoes: 0.17 kg CO2e/kg diced tomatoes
- Rice: 1.7 kg CO_2e/kg rice (90% white, 10% brown)

The functional units considered in this study include mass, serving size, calories, protein content, and a composite nutrient score. The recommended serving size of each product is based on common manufacturers' nutrition facts labels on commercially available products and industry standards (Almond Board of California). The following serving sizes are used in this study: rice, 45 g; almonds, 28g; tomato paste, 33 g; and diced tomatoes, 122 g.

The calorie content and protein content estimates for each food product are based on the U.S. Department of Agriculture's most recent database on nutrients in food (U.S. Department of Agriculture Agricultural Research Service 2013). Table 1 report the nutrient values assigned to each food product.

The composite nutrient score used in this analysis is drawn from Arsenault et al. (2012). Arsenault et al. used a regression analysis on real U.S. diets relative to a "Healthy Eating Index," or HEI. By doing so, the authors identified eight nutrient characteristics that were significant in determining the nutritional value of foods. Five of these characteristics contribute positively to nutrition; protein, fiber, calcium, unsaturated fat, and vitamin C. Three characteristics contribute negatively; saturated fat, added sugar, and sodium. Table 1 includes these eight nutrients for the food products considered in this study, as determined by the U.S. Department of Agriculture's Agricultural Research Service (2013).

The regression analysis results in the following algorithm for determining a weighted nutrient density score (WNDS):

$$WNDS = 100 \times (1.4 \times \text{g}\frac{\text{protein}}{50} + 3.3 \times \text{g}\frac{\text{fiber}}{25} + \mu\text{g calcium} + 2.51 \times \text{g unsaturated}\frac{\text{fat}}{44} + 0.37 \times \text{mg vitamin}\frac{\text{C}}{60} - 2.95 \times \text{g saturated}\frac{\text{fat}}{20} - 0.52 \times \text{g added}\frac{\text{sugar}}{50} - 1.34 \times \text{mg}\frac{\text{sodium}}{2400}) \qquad \text{Eq. 1}$$

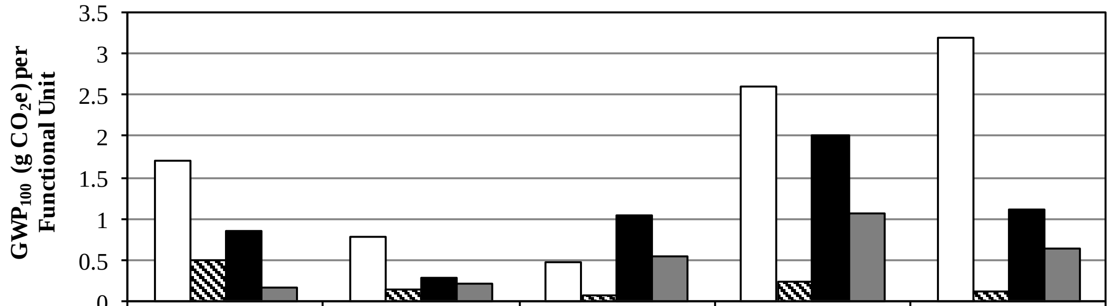
Table 1. Food product nutritional characteristics.

Characteristic	Unit	white medium and short grain rice, un-cooked	brown rice medium & short grain, un-cooked	Weighted average of 90% white, 10% brown rice	tomato paste	tomatoes, crushed canned	almonds, raw
g protein	per 100 grams	6.5	7.5	6.6	4.3	1.6	21
g fiber		2.8	3.4	2.9	4.1	1.9	13
mg calcium		3.0	33	6.0	36	34	270
g unsaturated fat		0.20	1.9	0.37	0.23	0.16	44
mg vitamin C		0	0	0	22	9.2	0
g saturated fat		0.14	0.54	0.18	0.1	0.040	3.8
g added sugar		0	0	0	0	0	0
mg sodium		1.0	4.0	1.3	59	19	1.0
kcal (food calorie)		360	360	360	82	32	580
g product	per 100 kcal	28	28	28	120	310	17
g protein		1.8	2.1	1.8	5.3	5.1	3.7
WNDS	na	15	19	15	94	86	75

3. Results

Greenhouse gas emissions, reported in units of kg CO_2e, vary widely for the four different food products, and also vary substantially within each food product depending on which functional unit is used (Figure 1). The WNDS-based functional unit is calculated using Equation 1 based on the mass of product needed for 100 kcal.

In four of the five FU cases rice performs worst, raw almonds perform best in all cases except the mass-based functional unit, and canned tomatoes perform best on a mass-basis and second best in all other cases.



	Per kg	Per Serving (×10)	Per 1000 kcal	Per 100 g protein	Per point of WNDS in 100 kcal
Rice (uncooked)	1.7	0.78	0.48	2.6	3.2
Raw almonds	0.51	0.14	0.086	0.24	0.12
Canned tomato paste	0.85	0.28	1.04	2	1.1
Canned diced tomatoes	0.17	0.21	0.54	1.06	0.64

Figure 1. GWP_{100} for four California food products using five functional units; mass, serving size, energy content, protein content, and a composite nutrient score.

4. Discussion

Results demonstrate how widely environmental impacts can vary, depending on the nutritional characteristic of interest. Due to high methane emissions from flooded field production, rice tends to have higher GHG emissions than the other three foods for all functional units, except for kilocalories. With its high carbohydrate content, rice delivers many more kilocalories than vegetables in any form, even the highly concentrated tomato paste, and therefore the environmental impacts are spread across more kilocalories. However, since white rice tends to be low in other nutrients, its impact on the basis of the WNDS is much higher compared to the other foods. Almonds perform better than rice on the basis of kilocalories, due to their high fat content. They also have an order of magnitude lower impact when assessed on the basis of protein, and even lower impacts when assessed according to their WNDS because of their high nutrient density.

Tomato paste offers an interesting case due to energy-intensive processing required to produce this concentrated product. While the intensive processing results in a relatively high emissions profile on a mass basis, it also serves to concentrate nutrients, balancing the higher emissions with a higher nutritional profile. For this reason, its GHG emissions profile per point of WNDS, while still higher than that for diced tomatoes and almonds, is not as distant from those two products compared to its profile on a mass, kilocalorie or protein basis. This analysis using the WNDS suggests that diets that are more heavily dependent on low-nutrient foods, such as rice, for functional nutrition, might incur higher environmental costs (as well as overconsumption of carbohydrates) than those that rely more on nutritionally-dense foods, assuming maintenance of a similar total nutrient content across diets.

Another observation that may be drawn from Figure 1 is that the WNDS seems to magnify differences among the products. In particular, the impact from rice looks significantly worse, while that from almonds looks much smaller, compared to the other foods. This is mostly due to differences in nutrient density of the two foods, but highlights the importance of transparent reporting when a composite nutrient score is used as the functional unit. Moreover, the WNDS, in this analysis, serves primarily as a mechanism for representing the composite nutritional density of a food based on a limited number of beneficial nutrients. Since all four of the food products are unprocessed or minimally processed foods that are generally considered healthy components of a diet, their WNDS are not highly affected by subtractions (in Equation 1) due to unhealthy factors, namely saturated fat, added sugar, and sodium. Evaluating the impact of these four foods when incorporated as ingredients in more processed products (e.g. almonds in a candy bar or tomato paste on a pizza) that have more of these unhealthy components, would present a more nuanced and complex use of the WNDS, and would more likely reflect the majority of actual consumption of these foods, than in the analysis here. In addition, changing science, subjective or culturally mediated notions of health, and the role of a particular food in a ‘balanced’ diet (meaning that almonds and rice are not likely to be substitutable in a diet), means that composite indicators such as the WNDS are likely to change over time.

It should be noted that the relative rankings of the four foods are also highly influenced by the environmental impact being assessed, which in this case is GHG emissions. This impact puts rice at a large disadvantage due to the peculiarities of its production system and its high methane emissions. If assessed on other impacts, such as other pollutant emissions or wildlife habitat provision, rice might perform as well as, or better than, the other foods, even with its lower vitamin and protein content. This is a well-understood shortcoming of carbon footprints, or any environmental assessment that focuses on a single impact category.

While researchers may be able to interpret or reinterpret FUs in a way that is meaningful to them, selecting a FU for LCAs targeting consumers is more challenging. A per-serving FU may make the most intuitive sense to a consumer, assuming the serving size reflects typical consumption. However, serving size does not capture the whole-diet or whole-meal perspective which may be important if environmental and dietary decisions are to be linked in a meaningful way in consumer labels. One lesson from our analysis is that presenting results using more than one FU might be desirable, in order to accurately convey the costs of different dietary values that might be of interest to different consumers. However, this approach also risks confusing consumers, if too many FUs show too many conflicting results.

5. Conclusion

Environmental and nutritional policies tend to be formulated in isolation from one another, sometimes resulting in sub-optimal recommendations, such as the advice to consume more fish from fisheries on the verge of ecological collapse. By combining LCA with nutritionally focused functional units, we can begin to bridge this gap between nutritional and environmental sciences and understand the true environmental costs of different nutritional profiles.

Though a recommendation on the FU for any particular study may be driven by a study's goal, audience, scientific developments (particularly with regard to nutrition and diet), or cultural or regional dietary differences, one recommendation applicable to all studies can be made: all LCAs of food products should report results in such a way that alternative functional units can be calculated by other researchers. Thus, a study using a FU based on a composite nutrient indicator should also provide results based on a reference flow such as mass as well as information on nutrient characteristics of the food. As indicated in the discussion section, determining the appropriate FU for consumer-oriented studies is more challenging. There may be ways for interested consumers to use diet calculators, or link shopping lists to LCA information to better understand their diet's impact on the environment. However, the choice of a FU for a consumer-oriented labeling scheme is still unresolved.

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