A Protein Quality Adjusted nutritional-LCA of Soy-Based Meat and Dairy Alternatives: Understanding the Environmental and Nutritional Implications of Food Processing

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1. INTRODUCTION

Efforts to address sustainability, food security, and health concerns have led to the rise of plant-based alternatives in high income markets. Plant-derived proteins generally have imbalanced essential amino acid compositions and lower digestibility than animal-derived proteins, yielding lower protein quality for human nutrition (Herreman et al., 2020). In this nutritional LCA (n-LCA), possible trade-offs between nutrient quantity and quality, and environmental impacts when replacing meat and milk products are explored. A novel *in vitro* protein digestibility protocol enables faster evaluation of food matrices for their protein quality (Sousa et al., 2023). By integrating a quality corrected (qc) -protein content, we offer a more holistic evaluation of processing plant proteins into meat and dairy substitutes.

2. METHODS

As nutrient delivery is a key function of food, the comparison between the products under investigation is based on the protein quality and nutritional density. We compare novel plant-based meat analogues (PBMA), a soy drink, and tofu to animal-derived products (milk and meat from dairy cows and broilers). The (potential) qc-prot in 100 g of food is determined by multiplying the protein amount in 100 g by the *in vitro* Digestible Indispensable Amino Acid Score (DIAAS). Representative data in the SALCA database (Nemecek et al., 2023) serves as the foundation for the Swiss agricultural production of animals and soybeans. The processing steps, including protein separation, were taken from Ecoinvent v3.9.1 and AGRIBALYSE life cycle inventory (LCI) database. Background inventories were adjusted to the geographical location when needed. Economic allocation was applied consistently for multi-output inventories in all processes. A “cradle-to-gate” system boundary is set for calculating the environmental impacts, whereas the nutritional values are measured “ready-to-eat”.

3. RESULTS AND DISCUSSION

The animal-derived products under investigation showed DIAAS values greater than 100 and can therefore be considered an “excellent” quality protein source for growing children. The same is true for the age group “older child, adolescent, adult” (not shown here). As the plant-based substitutes are only of “good” protein quality (<75 DIAAS > 99), adjusting the nutritional functional unit (nFU) from 100 g protein to 100 g qc-protein resulted in elevated environmental impacts (Figure 1). In the latter case, broiler meat becomes competitive with PBMA and tofu. Utilising soybeans from Brazil rather than Switzerland for the plant-based substitutes reinforced this trend (scenario analysis, not shown). Beef and milk cannot compete with plant-based substitutes. However, both show a high nutrient density. Given a fixed qc-prot content, only broiler meat requires 6 % less food intake compared to meat from cows (Table 1). Almost double the food intake for soy drink (+80%) and more than the double for tofu and PBMA (+136% and +119%, respectively), is needed to achieve the same qc-protein as the reference. This increased food intake results in more calories and higher sodium levels across all plant-based substitutes. Sodium intake can have detrimental effects on health and should be minimized. The increased calorie intake can lead to excess weight which raises the risk for non-communicable diseases. On the other hand, all plant-based substitutes were high in fibres and in case of minerals, the investigated PBMA was high in calcium and is enriched for iron but bioavailability, for humans from these sources, needs further investigations.

4. CONCLUSIONS

Processed plant proteins showed lower environmental impacts than beef and milk thoroughly. They are good sources of fibre, calcium, and iron (if enriched), but the consumption of similar protein contents results in a higher intake of calories and sodium compared to their animal counterpart. Total caloric intake and nutrient bioavailability from processed plant protein sources need to be carefully assessed in the overall diet.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Herreman, L., Nommensen, P., Pennings, B., & Laus, M. C. (2020). Comprehensive overview of the quality of plant- And animal-sourced proteins based on the digestible indispensable amino acid score. *Food Science & Nutrition*, *8*(10), 5379-5391. https://doi.org/https://doi.org/10.1002/fsn3.1809

Nemecek, T., Roesch, A., Bystricky, M., Jeanneret, P., Lansche, J., Stüssi, M., & Gaillard, G. (2023). Swiss Agricultural Life Cycle Assessment: A method to assess the emissions and environmental impacts of agricultural systems and products. *The International Journal of Life Cycle Assessment*. https://doi.org/10.1007/s11367-023-02255-w

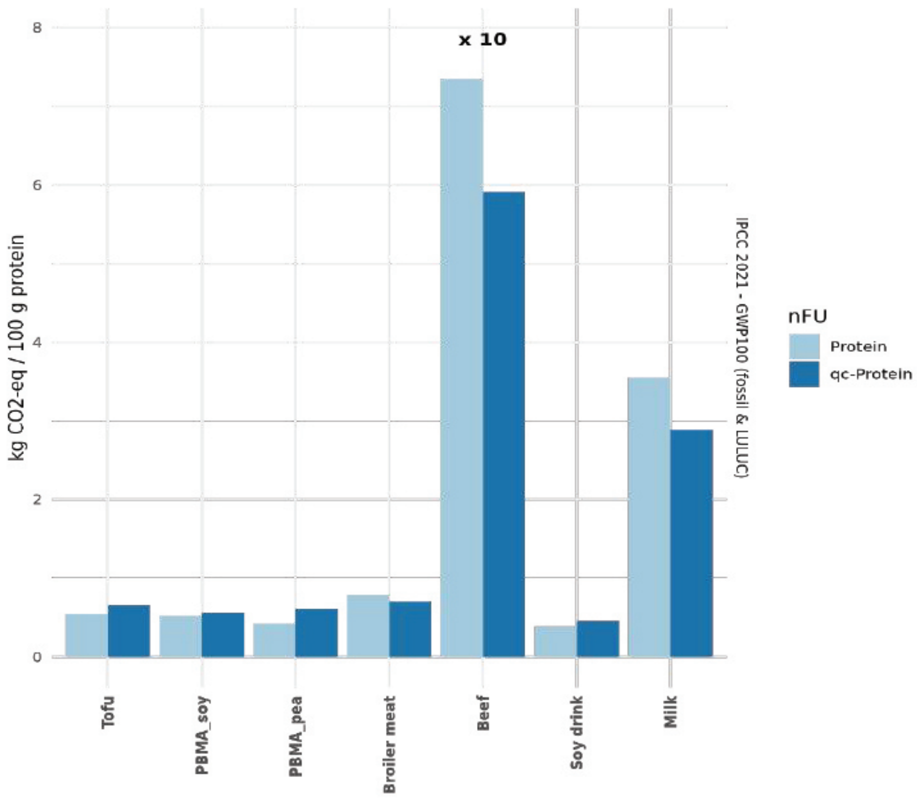
Sousa, R., Recio, I., Heimo, D., Dubois, S., Moughan, P. J., Hodgkinson, S. M., Portmann, R., & Egger, L. (2023). In vitro digestibility of dietary proteins and in vitro DIAAS analytical workflow based on the INFOGEST static protocol and its validation with in vivo data. *Food Chem*, *404*(Pt B), 134720. https://doi.org/10.1016/j.foodchem.2022.134720

Table 1. Given the same nFU (qc-protein), percentage difference for food intake and nutrient values is shown compared to meat and milk from dairy cows. Excess energy and sodium are detrimental to health and should be minimized (red, if greater than reference), whereas nutrients below qc-protein should be maximized (green, if greater than reference)

	Tofu	PBMA	Broiler meat	Beef burger patty	Soy drink	Cow dairy, 3.5% fat
Food intake	+136 %	+119 %	-6 %	Reference for Meat	+80 %	Reference for Dairy
Energy	+15 %	+49 %	-47 %		+85 %	
Sodium	+4 %	+85 %	-83 %		+80 %	
qc-Protein	0	0	0		0	
Fibre	n.a.*	n.a.	0		n.a.	
Calcium	+813 %	+ ~10^3 %	+25 %		-88 %	
Iron	+65 %	+471 %	-59 %		n.a.	
Zinc	-54 %	-71 %	-80 %		+35 %	
Cobalamin	n.a.	n.a.	-88 %		n.a.	

* n.a. = not available; not detected in reference (green) or in alternative (red)

Figure 1. Correcting for protein quality (dark blue) increases the global warming potential (GWP) of all plant-based alternatives per 100 g protein when compared to animal-derived products. Broiler meat becomes



competitive with PBMAs and tofu in GWP and land use (not illustrated here), but this is not true for beef and milk