Perspective

Precision Nutrition

OPEN

Why bioenhanced foods: role of food-based supplementation of bioactive micronutrients in public nutrition and health

Clara Y. Park[1], Xingen Lei[2], Kimberly O. O'Brien[3,]*

[1]Division of Food and Nutrition, Chonnam National University, Gwangju 61186, Korea, [2]Department of Animal Science, Cornell University, Ithaca, NY 14853, [3]Division of Nutritional Sciences, Cornell University, Ithaca, NY 14853.

* Corresponding author. Address: Kimberly O. O'Brien, Cornell University, Division of Nutritional Sciences, 230 Savage Hall, Ithaca, NY 14853. E-mail address: koo4@cornell.edu (K.O. O'Brien).

Suboptimal diet has been identified as a major risk factor for the global burden of disease.[1] Unhealthy diets can lead to malnutrition that encompasses undernutrition, micronutrient deficiencies, overweight, and obesity. While there is adequate food production in the United States, many key nutrients are consumed at amounts far below the dietary reference intakes. These nutrients have been labeled as "nutrients of public health concern" in the 2020-2025 Dietary Guidelines for Americans and include dietary fiber, vitamin D, calcium, iron, and potassium.[2] Other nutrients such as magnesium, folate, vitamin B_{12}, iodine, choline, and DHA are nutrients of public health concern for certain age, sex, and life stages such as pregnancy and lactation.[2] Individual food choices and dietary intake recommendations are not enough to overcome these gaps in nutritional intake placing many Americans at risk for chronic diseases that have been associated with nutrient deficiencies.

Over the decades, traditional methods have been used to address specific nutrient deficiencies including vitamin and mineral supplementation and food fortification. While supplements are helpful, targeting individual nutrients can be expensive and requires motivation. Individuals at higher risk of nutrient deficiency often have fewer financial and nutritional information resources, and are less likely to consume supplements.[3] Fortification is another approach that adds nutrients to a food during processing to increase its nutritional value. A well-known example is the fortification of cereal products with folic acid which has greatly reduced the incidence of neural tube defects in the United States.[4] Fortification approaches, however, are unlikely to be applied to all nutrients of public health concern. More recently, an increased focus has been placed on the need to alter nutrient consumption patterns using sustainable biofortification approaches. Biofortification involves enhancing the nutritional content or bioavailability of nutrients in food through fertilizers or environmental factors, conventional breeding, or genetic engineering. Increasing application of this approach has been centered on improving the nutritional content or composition of animal products. Animal diets have been modified to enhance the composition of meat or animal products (eg, eggs) by adding components to the diet such as grass, plant oils, fish oils, marine algae, oilseeds fat supplements, amino acids, and protein.[5] These approaches significantly impact the nutritional content of the food. For example, grass-fed beef has higher vitamin E content, and feeding microalgae to laying hens or broilers will increase the DHA content of the resulting eggs or meat.[6,7] Likewise, eggs and chicken are also enriched with the phytochemical astaxanthin through feeding laying hens and broiler chickens astaxanthin-rich microalgae.[8,9]

Nutritional enhancement of commonly ingested foods may be an economic and sustainable approach to alleviate nutrient deficiencies in the general population, but more studies are required to fully evaluate the bioavailability and possible health benefits to humans ingesting these bioenhanced animal products. As an example, 25-hydroxyvitamin D (25[OH]D), the precursor for the active vitamin D metabolite, has been added to the poultry diet to improve bone health and egg production,[10] but until recently little attention had been given to the 25(OH)D content of common animal foods,[11] and only recently, have studies begun evaluating the relative bioavailability of these vitamin D- and 25(OH)D-enhanced animal products.[12] Bioavailability of nutrients within foods may differ according to the food matrix, the total amount of nutrient ingested and the composition of the meal consumed along with the fortified food. Fat soluble vitamins are more easily absorbed in lipids, while minerals are known to be well absorbed in acidic environments. When evaluating results on nutrient absorption and utilization attention must also be given to the nutritional status of the study participant as nutrient bioavailability is typically regulated in response to nutritional status. Comparing data across studies is often challenging due to differences in study design, meal composition, study population characteristics, amount of the nutrient ingested, and differences in the timing of sample collections. More data are needed on approaches that can be successfully utilized to identify optimal amounts of bioenhanced nutrients in food and to identify ways to integrate these foods into the food supply to target those that will benefit most from these products.

Biofortification of the food system has many potential benefits, but caution is also required. Enriching the nutritional

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

Precis Nutr 2023;2(2):e00041.

Received: 17 March 2023, Revised: 20 April 2023, Accepted: 27 April 2023

doi: 10.1097/PN9.0000000000000041

content of commonly ingested foods may lead to excessive intakes, particularly for certain segments of the population with habitually high intakes, or for those with genetic backgrounds that may increase risk of adverse outcomes associated with excess nutrient accumulation. Increased attention has been focused on genetic variation in human populations and how this contributes to differential nutrient utilization and risk of common chronic diseases. For example, individuals with darker skin tones are at increased risk of low vitamin D status yet risk of low bone mass is significantly lower in Black persons compared to White persons.[13] Biofortification of the food system needs to account the genetic, cultural, and social factors that impact dietary intake and utilization of nutrients to optimize nutrient status while preventing adverse effects that may be associated with extremes of nutrient status.

As the nutritional content of meat and meat products is manipulated, attention is needed on the impact of these manipulations on animal health, product quality, economic considerations, product shelf-life, palatability and on the sensory qualities of the food.[5,14] Higher vitamin E content, for instance, may help prevent oxidation of fatty acids. Lipid oxidation decreases palatability and can lead to discoloration of meat which is detrimental to consumer sales. Reaching a beneficial level of biofortification requires multidisciplinary approaches that integrate precision livestock farming (using automated methods to enhance the health, welfare, production, and environmental impact of livestock farming) and livestock phenomics (systematic acquisition of high-dimensional phenotypic data). In addition, the possible environmental impact of producing bioenhanced foods must be further analyzed for this to be a means of sustainable food production.

Micronutrient deficiencies remain common in the United States. Intake of a healthy, balanced diet is a priority and bioenhanced foods may provide a means of achieving this goal particularly for nutrients of public health concern. More work is needed to personalize nutritional intakes in relation to life stage and biologic factors and to identify systems that can produce and deliver these foods. As food systems are transformed to promote human health and our knowledge on precision nutrition increases, nutrient biofortification strategies can be optimized to maximize health while preventing chronic diseases associated with suboptimal diets.

Funding

USDA Grant 2019-67021-29945, Chonnam National University (Grant number: 2023-0080-01). The supporting sources had no involvement or restrictions regarding publication.

Author Contributions

CYP, XGL, and KOO wrote the manuscript. KOO had primary responsibility for the final content. All authors read and approved the final manuscript.

Conflicts of Interest

None declared.

References

[1] GBD 2017 Diet Collaborators. Health effects of dietary risks in 195 countries, 1990-2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet 2019;393(10184):1958–1972. doi:10.1016/S0140-6736(19)30041-8.

[2] U.S. Department of Agriculture and U.S. Department of Health and Human Services. Dietary Guidelines for Americans 2020-2025. 9th Edition. 2020. Available from: DietaryGuidelines.gov. [Accessed March 1, 2023]

[3] Bailey RL, Fulgoni VL, 3rd, Keast DR, et al. Dietary supplement use is associated with higher intakes of minerals from food sources. Am J Clin Nutr 2011;94(5):1376–1381. doi:10.3945/ajcn.111.020289.

[4] Crider KS, Qi YP, Yeung LF, et al. Folic acid and the prevention of birth defects: 30 years of opportunity and controversies. Annu Rev Nutr 2022;42:423–452. doi:10.1146/annurev-nutr-043020-091647.

[5] Burnett DD, Legako JF, Phelps KJ, et al. Biology, strategies, and fresh meat consequences of manipulating the fatty acid composition of meat. J Anim Sci 2020;98(2):1–12. doi:10.1093/jas/skaa033.

[6] Tolba SA, Sun T, Magnuson AD, et al. Supplemental docosahexaenoic-acid-enriched microalgae affected fatty acid and metabolic profiles and related gene expression in several tissues of Broiler chicks. J Agric Food Chem 2019;67(23):6497–6507. doi:10.1021/acs.jafc.9b00629.

[7] Manor ML, Derksen TJ, Magnuson AD, et al. Inclusion of dietary defatted microalgae dose-dependently enriches omega-3 fatty acids in egg yolk and tissues of laying hens. J Nutr 2019;149(6):942–950. doi:10.1093/jn/nxz032.

[8] Magnuson AD, Sun T, Yin R, et al. Supplemental microalgal axtaxanthin produced coordinated changes in intrinsic antioxidant systems of layer hens exposed to heat stress. Algal Res 2018;33:84–90. doi:10.1016/j.algal.2018.04.031.

[9] Sun T, Yin R, Magnuson AD, et al. Dose-dependent enrichments and improved redox status in tissues of broiler chicks under heat stress by dietary supplemental microalgal Astaxanthin. J Agric Food Chem 2018;66(22):5521–5530. doi:10.1021/acs.jafc.8b00860.

[10] Mattila PH, Valkonen E, Valaja J. Effect of different vitamin D supplementations in poultry feed on vitamin D content of eggs and chicken meat. J Agric Food Chem 2011;59(15):8298–8303. doi:10.1021/jf2012634.

[11] Taylor CL, Patterson KY, Roseland JM, et al. Including food 25-hydroxyvitamin D in intake estimates may reduce the discrepancy between dietary and serum measures of vitamin D status. J Nutr 2014;144(5):654–659. doi:10.3945/jn.113.189811.

[12] Neill H, Gill C, McDonald E, et al. Bioavailability of vitamin D biofortified pork meat: results of an acute human crossover study in healthy adults. Int J Food Sci Nutr 2023;74:279–290. doi:10.1080/09637486.2023.2182256.

[13] Brown LL, Cohen B, Tabor D, et al. The vitamin D paradox in Black Americans: a systems-based approach to investigating clinical practice, research, and public health - expert panel meeting report. BMC Proc 2018;12(Suppl 6):6. doi:10.1186/s12919-018-0102-4.

[14] Tao L, Sun T, Magnuson AD, et al. Defatted microalgae-mediated enrichment of n-3 polyunsaturated fatty acids in chicken muscle is not affected by dietary selenium, vitamin E, or corn oil. J Nutr 2018;148(10):1547–1555. doi:10.1093/jn/nxy164.