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Food synergies for improving bioavailability of micronutrients from plant foods

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ABSTRACT

Plant foods are endowed with micronutrients but an understanding of bioavailability is essential in countries primarily dependent on plant based foods. Bioavailability depends majorly on food synergies. This review examines the nature of certain food synergies and methods to screen and establish it as a strategy to control micronutrient deficiency in the populations. Strong evidence on the synergistic effect of inclusion of vitamin C rich fruits and non-vegetarian foods in enhancing the bioavailability of iron has been demonstrated. Fat is found to be synergistic for vitamin A absorption. Red wine and protein have been explored for zinc absorption and effect of fat has been studied for vitamin D. Methods for screening of bioavailability, and biomarkers to demonstrate the synergistic effects of foods are required. Translation of food synergy as a strategy requires adaptation to the context and popularization of intelligent food synergies.

1. Introduction

There is a growing interest on the potential effects of plant-based diets on a range of nutrition and health related outcomes. This is especially important for countries with a predominantly cereal-pulse based vegetarian diet and also in countries where vegetarianism is on a rise due to several health related benefits (Key, Appleby, & Rosell, 2006). The thematic interest is in understanding how this food habit can be modulated to provide balanced nutrition especially in terms of micronutrients.

The key concept of attaining balanced nutrition in a plant based diet is food synergy which is defined as an additive or more than additive influences of dietary patterns, foods and food constituents on health (Jacobs, Tapsell, & Temple, 2009). In the context of micronutrients such as iron, vitamins A and D and zinc, this concept of food synergy relies heavily on bioavailability. Keeping bioavailability of micronutrients as a centre point and designing intelligent food synergy has the advantage of being close to population psyche but requires efforts to create them as national missions. Therefore, the available evidence with respect to foods and measurement of their additive effects on bioavailability of these micronutrients would come under the scope of this paper. The potential implications of such a food synergy in a habitual diet are large, in terms of improving micronutrient status at individual and population level.

2. Natural sources of micronutrients

Meat and meat products provide a major contribution to intakes of protein, iron, zinc, vitamins B12, A and D with high bioavailability. Conversely, compared with omnivorous diets, plant-based diets are reported to contain more of vitamin C, B vitamins, folate, provitamin A and D and E vitamins, antioxidants, phytochemicals and fiber, (Phillips, 2005) but less of bioavailable minerals such as iron, zinc and calcium and vitamins such as vitamin A, folate and vitamin D. A compilation of micronutrient content of various food groups based on food composition data base (Gopalan et al., 1999) is provided in Table 1. Out of the micronutrients compiled, dietary sources of vitamin D are limited to oily fishes, other non-vegetarian food items, irradiated mushrooms and some vegetables and rely majorly on fortified foods and sun exposure.

The four countries which are below the world average (45 kg per capita meat carcass mass availability) in per capita consumption of meat are India (5.2 kg per capita), Ethiopia (7.9 kg per capita), Burkina Faso (11.2 kg per capita) and Egypt (22.5 kg per capita) (FAOSTAT, 2014). All these countries have poverty, population pressure, urbanization, agriculture intensification and rely

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Table 1
Recommended dietary allowances for adults and micronutrient content of food sources per 100 g.

Nutrient	EAR M/F	Indian RDA	Plant foods					Flesh foods	
			Cereals, millets	Pulses, legumes	Fruits	Vegetables	Nuts, oilseeds	Meat, fish, egg	Milk
Iron mg	6/8.1	17/21	3.78	5.57	1.4	0.99	5.4	1.96	0.2
Vitamin C mg	75/60	40	0	2	30.2	40.6	0	0	1
Folate µg	320	200	25.1	133.7	12.2	57.8	83	60.77	5.13
Zinc mg	9.4/6.8	12/10	1.71	3.31	0.3	0.34	5.18	5.13	1.26
Vitamin B12 µg	2	1	0	0	0	0	0	3.5	0.14
Provitamin A µg	625/500[1]	600[1] 4800	36.4	158.8	241	1763	–	1508[2]	42[2]
Vitamin D µg	10	ND	ND	ND	ND	0.29 6.67 for mushroom (D2)		Meat 0.96/Salmon 16.5/egg 5.5	Yoghurt 0.95

EAR, Estimated average requirement; M/F, Male, female; RDA, recommended dietary allowances; ND, not determined. [1]vitamin A requirements, [2]values indicate µg of vitamin A. Indian RDA is based on predominantly vegetarian diet (ICMR, 2010). EAR based on IOM accessed from www.nap.edu.accessed on 7/9/2016. Compositions presented are averages of commonly consumed foods in a food group (Gopalan et al., 1999). Values for vitamin B12 and D are from USDA National Nutrient Database for Standard Reference 28 Software v.2.3.8.

predominantly on a cereal based diet with small amount of non-vegetarian food. They suffer from high prevalence of deficiencies of micronutrients; iron and vitamin A (UNICEF., 2006) and would benefit from plant-food based synergies for enhanced micronutrient bioavailability. Though such countries may adopt varying strategies of addressing micronutrient deficiencies; dietary diversification which alone will be looked upon to sustain the efforts of eliminating micronutrient malnutrition since dietary diversity has been envisioned as an integration of agriculture and nutrition and the countries mentioned above belong to an agriculture-based society.

3. Bioavailability of iron, vitamin A and zinc

Iron, vitamin A and zinc have been identified as micronutrient deficiencies with global prevalence. Though the content of these nutrients or their precursors is an issue, the deficiency prevalence is quite high in countries which majorly rely on plant based diets due to poor bioavailability.

The major form of iron present in plant based food is non heme iron. Non-heme iron absorption is inhibited by phytic acid (6-phosphoinositol) which is found in whole grains, lentils, and nuts. In addition, polyphenols, such as tannic and chlorogenic acids, found in tea, coffee, red wines, and a variety of cereals, vegetables and spices also inhibit iron absorption. The sources and inhibitors of zinc absorption are also similar. Plant foods rich in zinc—such as legumes, whole grains, nuts, and seeds—are also high in phytic acid (Hunt, 2003). An estimate of iron absorption has been deduced for Indian diet based on previous reports which is 5 per cent for adult male and 10 per cent for adult female (Nair & Iyengar, 2009) and is low compared to 12–15% suggested for Western diets (FAO/WHO, 1998). For zinc, 30–35% absorption has been suggested (Hunt, 2003). Stable isotopic studies in Indian adolescents also reported 8% absorption of iron and 31% absorption of zinc from habitual rice based meal (Nair et al., 2013). Based on National data (NNMB, 2012), an intake of 11 mg/d iron has been reported for the same group which would translate to 0.864 mg/d from a habitual meal. For zinc, since National data is not available a zinc intake of 2.6 mg/ meal (Nair et al., 2013) has been considered and the absorption would be 0.78 mg per meal apparently requiring modifiers to satisfy the daily requirement.

In the case of provitamin A carotenoids, the bioavailability and bioconversion are influenced by micellerisation at the absorptive enterocyte. Factors such as food matrix, localization of carotenoids within the cell matrix of plants and type and source of fat, all modulate the extent of micellerization. The wide range of bioconversion ratios of 3.6–28 of β^- carotene to vitamin A reported demonstrates this effect (Tang, 2010). Here, the food – matrix related complexities majorly refer to the presence of dietary fiber in varying quantities from fruits and vegetables. Dietary fiber has been reported to interfere with micelle formation by partitioning bile salts and fat in the gel phase of dietary fiber. Intracellular location of the carotenoids in the plant food and the intactness of the cellular matrix are certain other matrix-related factors which may affect absorption and bioconversion in varying proportions. The food synergies associated with the two forms of vitamin D i.e. ergo calciferol (D2) and cholecalciferol (D3) present in diet have not been studied extensively but attempts have been made to assess food synergies that would potentiate absorption from supplements (Borel, Caillaud, & Cano, 2015).

Due to the low bioavailabilities reported for iron, provitamin A, vitamin D and zinc, it is imperative to explore beneficial food synergies to enhance and if possible, overcome the factors which negatively affect bioavailability from plant based diets.

4. Measurement of bioavailability

Designing evidence based food synergies not only require understanding the physiology of digestion and absorption and interactions of the micronutrients with the dietary ligands but also need a robust high throughput micronutrient bioavailability screening methods (Fig. 1).

4.1. In vitro methods

4.1.1. Cell free system using dialyzable nutrient

A commonly used *in vitro* method involves simulated digestion with pepsin as gastric stage followed by a digestion with pancreatin and bile salts as the intestinal stage. The proportion of the

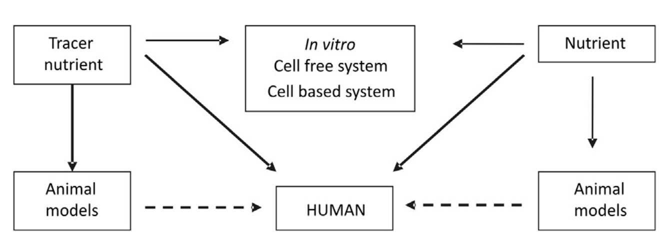

Fig. 1. Methods for predicting bioavailability of nutrients in human.