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Toward the redesign of nutrition delivery

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A B S T R A C T

In the facilitation of widespread access to low-cost, good tasting food, the global food system has relied on the use of fat, sugar, chemical processing aids and plastics, among other elements potentially detrimental to human health and the environment. This contrasts starkly with the strategies of natural nutrition delivery systems. Rich in vitamins, minerals, and other substances of functional benefit to human health, natural delivery systems, such as fruits and vegetables, retain their physical and chemical stability in a range of conditions over relatively long times through protective skins and shells that can either be eaten or degrade rapidly and fully in nature. Frequently natural foods can be delivered in small (even extremely small) portions, as with berries, insects, plankton and krill, permitting portion control and the rapid and efficient delivery of functional nutrition in inherently mobile circumstances. These and other qualities, which have insured the sustainable and healthy nourishment of animals and humans for at least tens of thousands of years, are often absent from today's man-made food and beverage delivery systems. With growing awareness of the liabilities to maintaining the food system of today, efforts are now underway to redesign nutrition delivery so as to provide the contemporary benefits of global access while retrieving the health and environmental benefits associated with natural delivery systems. We review these here, with special attention to recently commercialized nutritional delivery systems emerging from the drug delivery field aimed at reducing waste in food and beverage (nutritional aerosols) and eliminating waste in food and beverage packaging (edible skins). We briefly discuss the potential ramifications to how we will eat tomorrow.

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1. Introduction

To support the needs of a growing human population, the modern food system has evolved into a professionally managed, technology-savvy, trillion-dollar global industry. Never before in history has so broad a swath of the population had such easy and continuous access to such a wide range of foods at such affordable prices. This unprecedented era of plenty has been enabled by a diverse set of technologies employed by the global food industry to provide the developed world with safe, inexpensive, good tasting food.

The success of this era of plenty has however led the human population to the brink of a new and paradoxical era. Abundant global access to inexpensive food has produced growing and potentially catastrophic health and environmental problems.

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Obesity now afflicts 35% of the U.S. population over age 20, relative to only 13% in 1962 [1]. The combined prevalence of overweight and obese people presently stands at 69% of the U.S. adult population [1]. Excess calories and an imbalance in the kinds of calories we consume aggravate serious health conditions, like diabetes. According to the U.S. Department of Health and Human Services [2], there were an estimated 57 million adults with pre-diabetes, and 24 million with diabetes, most of whom possessed type 2-diabetes, a strongly diet-related disease. As published in the American Journal of Clinical Nutrition [3], obesity is a contributing factor in the U.S. to approximately 100,000–400,000 deaths per year, and according to the US Surgeon General [4] is costing U.S. society an estimated $117 billion in direct and indirect costs.

Other factors in the current food system can exacerbate these and other health problems. To aid processing, extend shelf life and enhance the consumer appeal of foods, artificial chemicals are added throughout the growing and processing of most modern foodstuffs. Packaging of processed foods further introduces artificial chemicals (e.g. phalates and other petrochemically derived plasticizers) into our food supply [5]. The health consequences of these chemicals, including artificial colorants, flavorings, preservatives, lubricants, propellants, and texturizers, are largely unknown, though there is no recognized nutritional value to these materials [6]. Artificial materials in foods, and especially in food packaging, can also lead to materials that endure in the environment for thousands of years after a single consumption. Given the current rates of global plastic production (estimated at 280 million tons in 2011) [7], the environmental consequences are extreme. Adding to this environmental burden, as much as 50% of all food is wasted from the field to ultimate consumption [8].

To counter these trends and to guide humanity back to the inherent benefits and sustainability of the natural food system, while maintaining the capacity to feed the human population in contemporary conditions, insights and delivery technologies from the pharmaceutical industry are combining with an increasingly refined understanding of natural nutrition delivery systems, broadening the notion of what it means to eat.

The following review summarizes this trend with a special focus on two recent technologies aimed at the personalization of nutrition and the elimination of waste in food and food packaging.

2. Diminishing excess in food & beverage

Current efforts to enhance nutritive value and diminish excess in food and beverage products trace back at least to the origins of food fortification. Nutrition fortification strategies, consequent to the discovery of vitamins, and the mass-scale production of synthesized vitamins and supplements throughout the 19th and 20th centuries [9], have helped to diminish the prevalence of vitamin deficiency and associated illness around the world. Recommended Dietary Allowances (RDAs) [10], among other federally regulated food fortification guidelines of the FDA, exemplify such strategies. More recent efforts to increase the functional benefits of foods date back to the 1980s.

2.1. Functional nutrition suspensions and dispersions

The notion of functional food was introduced in 1984 by Japan's Ministry of Education, Science and Culture (MESC) in response to the nation's growing senior population, initiating large-scale research efforts to discover and develop new essential food functions [11,12]. As defined by Japan's MESC, functional foods must 1) provide the primary function of delivering essential nutrition, as required for human survival, 2) contain tastants to stimulate sensory organs and 3) encompass a tertiary physiological function aimed at directly or indirectly preventing disease [12]. In 1991, Japan's Ministry of Health and Welfare further defined the functional food market by becoming the first government institution to establish a functional food regulatory and labeling system, Foods for Special Health Use (FOSHU) [11]. The US followed shortly thereafter with the Dietary Supplement Health and Education Act (DSHEA) of 1994, allowing functional food companies to state structure/function claims on products [13]. The ability to make these claims has since encouraged food and beverage companies to produce functional foods, through the introduction of active ingredients in dispersion and suspension forms, further increasing the wide array of functional nutrient products targeted to improve human health [9]. Indeed, with expected annual growth rates of 10% and a projected global market value exceeding $100 billion for 2013, functional foods are becoming a dominant trend in the food and beverage industry [14].

The functionalizing of drinks, adding concentrated nutrition and thereby progressively reducing the “waste” of empty calories in the beverage product, has become a major trend in food and beverage [15]. The functional beverage market began with the development of Gatorade, and Red Bull, and today includes a wide range of vitamin waters and fortified drinks [15,16].

The functionalizing of nutrient powders is another contemporary trend, with multiple benefits including extended shelf life and consumer convenience. These powders, which provide high concentration of nutrient per gram of food, have ancient precedent [17], but the present plethora of high-nutrient concentrated food powders, from the early Nescafe® and Lipton's Cup-a-Soup® to the full range of dried food powders found in stores today, particularly benefited by the invention of spray-drying and freeze-drying (lyophilization) [18]. Many of these products use particle engineering to decrease dissolution times and improve consumer experience by modulating particle size, porosity, hydrophilicity, and other properties of the powders, or, indeed, by microencapsulation. The latter may be introduced to prevent degradation of the nutrient before it reaches the desired functional location, for instance with functional nutrients such as probiotics, which benefit from microencapsulation to avoid acidity of the gut [19], or fish oil, which provides a wealth of omega-3 related nutritional benefits, and, once encapsulated, avoids oxidization and unpalatable taste [20].

The trend over the last couple decades toward the functionalization of suspensions and powders, to be integrated into foods for ingestion, has an obvious precedent in the development of medical suspensions and powders in oral delivery forms, notably liquids and pills, for the treatment of a large variety of medical conditions. In the same way that, at least from the 1970s, researchers started to pioneer better ways to deliver drugs, using patches, gums, aerosols, creams, among other novel delivery systems, thereby redesigning the delivery of medicines to improve safety, efficacy and convenience, researchers are starting today to redesign the delivery of food, in this case to deliver nutrition with greater potency, less waste and better convenience.

2.2. A new form of waste-free functional nutrition

Edwards et al. [21–23] proposed a nutritional delivery system, referred to here as “Inertial Digestive Aerosol Particle” (IDAP) Nutrition, drawing on advances in aerosol drug and vaccine delivery systems, notably in the aerosol drug delivery field [24,25].

IDAP Nutrition refers to a dry, highly aerosolizable nutritional dispersion that enters the mouth via the force of a consumer's breath and targets the digestive tract. IDAP Nutrition avoids lung penetration by special design of the aerodynamic diameter and modification of traditional dry powder aerosol delivery systems to enhance inertial deposition of the powder in the mouth following the force of the consumer's breath.

IDAP Nutrition, when compared to traditional liquid sprays, which may also deliver nutrition via the air to the mouth, can deliver two or more orders of magnitude active material per mouth delivery. Liquid sprays require the dilution of nutrition in water or water/alcohol solvents to permit delivery from a metered dose inhaler or pump spray [26]. Concentrations of nutrition exceeding 1% of the total mass of the liquid tend to increase viscosity and lower the efficiency of delivery from the device. Given that a typical mass delivery from dry or liquid

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