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Looking into the future of foods and health

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Abstract

The health of the population is compromised by poor dietary choices. Resolving this situation will require a substantial investment at many levels of science, agriculture and food industrialisation. If such investments are undertaken they will provide the opportunity to change the food marketplace from a product centric, to a consumer centric, strategy competing to deliver health benefits to individuals.

Keywords

food; health; assessment; personalising; metabolomics food reformulation

THE NEED: HEALTH VARIATION IN THE POPULATION

The food industry has a unifying goal to deliver to the marketplace safe, convenient, affordable and delicious food products that provide consumers the means to assemble the diets that maintain and improve their health. Scientific research has built considerable basic knowledge that has been instrumental in achieving this goal. Examples of prior success abound, from the scientific discoveries of the essential nutrients to the engineering of unit operations that ensure the reliable and controlled lethality of potential food borne pathogens in food processing lines. This knowledge ensured that the population consumed foods that provided all of the essential nutrients within a normal diet and was protected from the broad range of food borne microbial pathogens in the environment. The overall success of the industrial translation of this science is illustrated by the observation that most of the Western population is now unaware of, that is, has never seen the phenotypes of diseases caused by classic deficiency diseases, iodine – goitre, vitamin C – scurvy, vitamin A – blindness, and rarely experiences food borne illness from the consumption of industrialised foods.

Consistent and sustained efforts by various health organisations at the local, federal and international levels, working with the food industry and regulatory agencies are addressing the diseases that are caused by overt, frank deficiencies of essential nutrients in the developing world (Chakravarty and Sinha 2002). Even in the developed world there remain instances whereby unusual lifestyles lead to dietary patterns that produce inadequacies of particular nutrients (Smotkin-Tangorra et al 2007; Aung et al 2006). Nonetheless, these are rare and usually recognised quickly for what they are, conspicuously unusual and inappropriate food choices. Again, by the nature of essential nutrients such deficiencies even if caused by unusual diets can be resolved simply by fortifying with appropriate vitamins and minerals (Cannell et al 2008).

Over the past several decades, as food choices and the food marketplace continued to change in response to convenience, affordability, and of course delight, food intakes began to reflect more and more these food choices based purely on preference (Moskowitz et al 2005). Consumers reacted very positively to the wide variety of choices and the diversity of apparent choices increased. Food products and the food marketplace in general have experienced a prolonged expansion of diversity. Consumers genuinely have the luxury of choice of different food products and they embrace this luxury in choosing the foods that they prefer. Dietary intakes needless to say, have become increasingly dominated by the composition of those foods that appeal to convenience, affordability and taste and flavour preference (Sebastian et al 2008).

Through the past three decades, although nutrient deficiencies have not increased, diet-related diseases have (Alberti 2001). These new health problems though related to diet are not due to deficiencies but to imbalances in overall macronutrient contents relative to the lifestyles of those consuming them. Disturbingly, imbalanced diets have apparently become widespread across the world leading to diseases including atherosclerosis, obesity, diabetes, hypertension and osteoporosis (Lopez et al 2006). Furthermore, several diseases such as cancer, inflammatory disorders, neurodegenerative diseases and autoimmunities that while not believed to be explicitly caused by diet are either accelerated or delayed depending on dietary choices implying that diet could significantly improve the global burden of these problems (Locke et al 2005).

HUMAN HEALTH STATUS

Food and nutrition research thus have a new challenge for the 21st century that parallels in many ways the challenges at the beginning of the 20th century. The devastating and widespread diseases that were epidemic in the 19th century and were caused by nutrient deficiencies were resolved during the 20th century by a massive global scientific and industrial effort extending across the entire agricultural enterprise (Backstrand 2002). The solutions for health problems caused by imbalanced diets will require a similar investment in science partnered by all aspects of agriculture and food (Daar et al 2007). A combination of research knowledge and food applications must continue to provide consumers with diets that maintain the value systems of safety, quality, stability, convenience and cost. These values are not sufficient. While we do not yet know what the solutions to the problems of poor diets and the metabolic diseases that they produce, nonetheless certain elements of the solution are already clear. Whereas the great successes of essential nutrients were achieved by viewing humans as a relatively homogeneous population, this will not be true for the next generation of diet-related diseases. Diets must also ensure that each consumer as an individual maintains optimal health within the lifestyle that they choose to pursue. This is the great challenge of diet and health, not to provide a standardised food that fits the mean of the population, but to provide the means for individuals in the population to achieve their aspirations for their own personal health. To reach this goal, science will first have to build and technologies bring to practice an actionable understanding of human health including its diversity.

Assessing human health

The biological truth is that individual humans differ in their health in many of its aspects as a result of genetics, life state, life history and all of the external influences that make up an individual’s environment (Fay and German 2008). Therefore any attempt to successfully guide individuals towards a health status that supports the lifestyle that they choose for themselves and prevents the development of diseases associated with that lifestyle will require supporting diets, lifestyle, even clothing, designed to recognise and address those differences in health.

First and perhaps foremost, health itself is highly complex and cannot be defined in simple terms linked solely to disease (Lange et al 2006). For example the complexity of the interactions between diet and health are being revealed due in no small part to the catastrophic failures in metabolic regulation and health millions of people are experiencing around the world (Popkin 2006). Metabolic health can be loosely defined as the successful management of energy requirements of a particular lifestyle with appropriate energy (calorie) intakes, storage and effective mobilisation; energy efficiency, fuel partitioning and prioritisation. When successful, individuals consume precisely the calories that their lifestyle requires, store a suitable storage buffer and mobilise this storage according to acute needs. What would seem simple is clearly not. We are now experiencing a literal global pandemic of disorders due to failures of ‘simple’ metabolism. However, while metabolic imbalance is the central theme, ie excess caloric intake, the expression of this imbalance varies widely across the population. Some experience obesity caused by excessive intake of energy substrates (fats, carbohydrates or potentially even protein or alcohol) (Popkin 2006), others suffer type 2 diabetes apparently caused by inappropriate clearance and storage of energetic intermediates (lipids, carbohydrates) (Wang et al 2008; Schulze et al 2005), some experience premature atherosclerosis caused by a failure in the transport of energy intermediates (complex lipids) (Ordovas 2003). Hence, no intervention in metabolic health, either pharmacological or nutritional can be foreseen to be the same for all consumers.

If individuals should consume diets based on their personal health, how will they know what their health is? It will be necessary to build technologies based on measuring assessors/ diagnostics that reflect each individual’s health with sufficient accuracy to be actionable. This fundamental truth is already a well established fact in therapeutics in which sophisticated technologies have evolved to diagnose individuals for diseases that are a departure from normal or healthy and to design drugs to treat their specifically diagnosed diseased state. It will be necessary to develop comparable assessment approaches to diet dependent health. While this may sound overwhelming, it is not. Scientists are developing the knowledge, technologies and bioinformatic tools that will be needed (German et al 2005a; Gibney et al 2007; Schoenhagen and Nissen 2006; Lemay et al 2007; Sajda 2006).

Will consumers accept a more personal view of diet and health if it requires a more invasive assessment system? Humans are for the most part reconciled to routine diagnostics and this loss of privacy and personal control is accepted because of the fear of undiagnosed and untreated disease, by demands of medical insurance mandate and the comfort of cradle to grave familiarity with the process. However, in order for food to succeed with a science based wellness strategy, customers must first subject themselves to assessment of their basic health status. There is no obvious precedent for this in the food industry, yet there are abundant examples from other consumer sectors. Customers are prepared to accommodate to assessment for other aspects of wellness/quality of life. Examples of such assessment strategies are size measurements for apparel, weight measurements for safety devices, ability measures for athletic equipment, skin and hair assessment for cosmetics and optical calibration for eye glasses. It is now time to take an aggressive approach to define precisely what is necessary to make individualised health a reality, and then to make it so. Also as in any other aspect of the consumer marketplace, sophisticated decisions require educated consumers. Hence education will be a central element to the development of more personalised health and the success of various solutions as consumer products.

Health assessment as metabolic response to food

Health is a fundamentally difficult concept to define much less to measure. We are confident that disease is a failure of health and at present most definitions of health simply refer to the absence of disease (Webster’s unabridged Dictionary 2008). Nonetheless, although science may not have the tools to measure gradations in personal health, consumers are well aware of the variations in not only their own health status through their lives but the disparity in their health relative to their peers and family members. Thus consumers are looking for various means to improve their own health. A wide range of consumer products and services address this consumer desire. The pursuit of greater health is most evident in physical performance. Exercise equipment, trainers and supplements, apparel and a variety of food and beverage categories service the consumer who is pursuing exercise as a means to improve their health. Assessment of the results of exercise is one of the most important drivers of success. Individuals who choose to exercise use relatively low technology devices to assess their performance (time to run defined distances, maximum weight lifted, repetitions of weight raised, heart rate through a defined duration and distance). Though simple, the feedback that these assessors provide to individuals are a key part of the sense of accomplishment and the net satisfaction that the exercise process and all of the affiliated accoutrements are of health value. The principle is established, health is the ability to respond to environment, from protection from pathogens to desires for performance, just how far and wide can human health be defined and measured?

The most obvious role of diet in human health is through the provision of metabolic substrates and fuels (German et al 2005a). Metabolism in humans and animals, within cells and across tissues is the quantitative interaction of metabolic pathways with acute physiological demands and the ensemble of metabolites introduced by eating. The varying 'health' of individual metabolism is a concept that has attracted scientific research for decades. The hallmarks of many of clinical medicine's biomarkers of health are simple measures of metabolites as direct indicators of metabolic fluxes which in turn are considered to reflect the overall robustness of metabolism. Blood cholesterol, triglycerides, glucose, free fatty acids and homocysteine all provide relatively predictive measures of deviations of individual metabolism from an idealised, ie healthy phenotype (Colhoun 2007). Thus, metabolism as an accurate reflection of human health is likely to be the next growth phase of assessment.

Metabolite concentrations are the direct reflection of metabolism. Measurements of metabolite concentrations, when comprehensive and accurate, reflect the range of biochemical effects induced by a condition or intervention. Metabolomics is a post-genomic science that seeks to measure all of the metabolites in a tissue, biofluid or cell (German et al 2005a). Metabolomics as a field has the power to build scientific knowledge of human metabolism and because measures of metabolites can be taken on an absolute abundance, measures taken in scientific studies can be immediately translated to direct applications to health and medicine. The tools of metabolomics are still in the process of development. No single approach can measure all metabolites at the accuracy necessary. Nonetheless, tools that are able to accurately measure a subset of metabolites are already being used to identify the functions of genes, describe the effects of toxicological, pharmaceutical, nutritional and environmental interventions, and to build integrated databases of metabolite concentrations across human and research animal populations (Raamsdonk et al 2001; Nicholson and Wilson, 2004; Gibney et al 2005). When these measures are considered to be a reflection of the entire metabolite pool, ie metabolomics, data can be used to diagnose or predict disease, to stratify populations by individual's specific metabolism, or to determine the safety or efficacy of a therapeutic intervention (Zeisel et al 2006). Metabolomics can also be used to directly quantify and assess the consequences of eating. The only additional consideration is to include measurements of metabolites as a function of time after eating a standardised meal (ensemble of components).

The idea of assessing post-prandial metabolism has gained acceptance, with the ability of an individual's response to a standard glucose challenge to predict insulin sensitivity prior to the development of metabolic diseases of insulin failure (Haeckel et al 2006). To date, the use of metabolic measurements for assessing health status has been approached as an application of single biomarkers designed for diagnosis or prognosis of disease, with the most obvious example of cholesterol (Grundy 2002). As the tools improve, health itself will begin to be measured with this same perspective measure individually to act personally.

Metabolomics is bringing a different approach in measuring metabolism more comprehensively by increasing the scope of measurements that can now be made with modern analytical equipment and more biologically by the translation of those methods into biochemical pathways. Because the products, intermediates and substrates for virtually all endogenous biochemical pathways are known and the intermediates can be measured by various analytical platforms, it is now possible to assemble a picture of individual health in its fuller context. This is already providing advantages for both discovery and clinical work in disease, but could be equally powerful in developing an understanding of the relations between metabolism and performance and even extending to the interaction between metabolism and taste sensation and olfactory preference development (Rezzi et al 2007).

Metabolism will be described comprehensively in breadth and depth and time. Rather than single metabolites, more comprehensive sets of metabolite measurements are obtained by multi-parallel analyses. Rather than averaging over large populations or trials, measurements of the metabolic profile of single individuals become discretely targeted information, and rather than attempting to identify a key point in time, measurements are taken as a function of time after various challenges, including diet, to reflect the true dynamics of metabolism.

Changing food composition to accommodate to personal health

The successes of solving diseases caused by deficiencies of essential nutrients required an understanding principally at the level of individual molecules: vitamins, minerals, fatty acids and amino acids. That is to say the essentiality of a vitamin was independent of its source and since everyone needs all the essential nutrients, personalisation was not required in foods to deliver a unique set of nutrients to only a subset of the population. This luxury of being able to focus solely on individual molecules will not be true in the future. A more personalised future will require not only that foods be compositionally defined, but that composition itself can be customised for particular consumers. Again, this may seem to be a fond wish for a distant future, but in many respects it is already here. Over the past 50 years food science has assembled a predictive knowledge of the biomaterials that make up foods (deCampo et al 2004; McCarthy et al 2006). Driven by the needs to improve safety, stability, structure, cost and convenience, the modern food toolset is capable of producing different food products using a wide variety of ingredients (Bruin and Jongen 2003). This same knowledge and engineering dexterity can be easily applied to formulating the same food products for enhanced nutritional values to a more diverse and customised consumer marketplace.

As a simple example, wheat flour has been the traditional functional ingredient core of a vast array of final dough-based products from breads to pastas and pastries. However, approximately 2% of the population is now known to be intolerant to gluten protein and for these consumers such wheat based dough products, though desired are literally toxic (Sakly et al 2008). For each of these product classes, alternatives to the core functional ingredient (wheat) have been developed using a variety of commodity protein, carbohydrate, fat and oil sources that are able to develop the products with no contaminating wheat gluten to those who value the food products, and yet need a ‘personal’ formulation (Niewinski 2008). These same principles will be applied across a wide variety of food product classes, formulations and health targets.

One of the important challenges of providing foods with more personal health propositions is that some aspects of the variables of foods that impact on diet and health have been ignored. The structures of complex biomaterials as foods, including the simple macronutrients protein, fat and carbohydrate, but also nonessential, even indigestible components, are vital to their effects on health. Science must recognise and build a detailed understanding of this extra dimension of food's effects on health, food structure, and industry must learn to control it.

The scope of diet and health became much larger when it was recognised that we are not just feeding ourselves, we also feed our intestinal bacteria and this dimension of health is both important and personal. From the narrow perspective of viewing diets solely for their ability to meet the needs for all essential nutrients, the biological activity of our travelling partners, commensal bacteria are not particularly important. However, as we strive to understand the complex interactions between diet and overall health, the physiology, metabolism and population ecologies of the massive microbial populations that co-inhabit our bodies must be considered and their health fed appropriately as well (Xu et al 2007).

Finally, the status of essential nutrients could be accurately determined in the fasted condition. This allowed scientists to ignore the multiple aspects of our temporal responses to foods. The time dependence of foods: when we eat, the effects of food structures on the delivery of nutrients and the need to coordinate in time our demands for fuels with their provision, will need to be considered as a critical aspect of the diet – health axis both scientifically and industrially. Once again, this means that we have to understand the effect of intestinal dynamics and the role of food structure and composition that adding this temporal component to the composition of foods will enhance their quality. And, while it may at first seem to be something that is decades away, providing specific foods with specific formulations to specific consumers at specific times, is already in practice in for example athletic facilities around the world (Lacroix et al 2006).

The ultimate success that will follow the personalisation of foods is as much economic as scientific. The core to the future of human health from a scientific perspective is now understood to be more personalised diets. Yet the concept of personalised foods is considered to be disruptive to the food industry's financial structure. At present, profitability in the food industry is based on cost reductions achieved through economies of scale in purchasing, processing and marketing. It would seem transparently obvious that a personalised approach to foods is impossible within an industrial model based on producing vast numbers of recognisable (branded) identical food products, marketed and distributed around the world. However, personalisation of taste, color, texture, convenience and even safety are already in place in today's food marketplace. Each adds value and enhances the brand recognition and loyalty for food producers. Nutrition value is not revolutionary, though the channels that producers use to 'find' the customers and vice versa may indeed change (Moscowitz et al 2006).

Linking food composition to health assessment

The public health problem of avoiding deficiencies of essential nutrients was resolved by a massive investment in scientific knowledge, in the chemical analysis of agricultural commodities and food products for their content of essential nutrients, in a coordinated system of agricultural management, industrial food processing oversight, food fortification and enrichment, in ongoing surveillance of the population's diet and health and in the development and implementation of dietary guidelines. This investment was needed to match the various food choices available within an overall diet to adequate intakes of all essential nutrients. Personalising foods for metabolic health will likely take a similar path initially. Metabolic health depends on more than just the essential nutrients, therefore food composition databases will need to be more complete for optimizing personal health. Non-essential nutrients, secondary plant metabolites, proteins, lipids, saccharides, nucleotides, the presence and activity of enzymes, the structures of macromolecules and tissues all of which are recognised to affect the health value of food products will be the information basis for redesigning foods. Databases are being updated by agencies such as the US Department of

Agriculture (USDA) to include more detailed information about each agricultural commodity (Holden et al 2008). These data will be the palette with which future foods and diets are designed. The values that particular compositions provide to food product designers and individual consumers will also dictate in part the evolution of value in agricultural commodities. Food materials with unusually active components will be more and more valuable as individuals who can take most health advantage of those components recognise that these materials are available and provide health properties for their personal health needs.

Designing foods

The most important driver for health as a discrete value in foods is the appreciation of its importance to the health of the consuming public. The previous sections described the steps that are in the process of being put in place to provide consumers with the ability to gain knowledge of their own health and the value of foods, and other goods and services to improve it. In such a more educated marketplace populated with consumers armed with self-knowledge of their health needs, the food industry and its supporting agricultural enterprise can begin to deliver foods that apply their expertise and skill in food manufacturing to deliver products that target the health of consumers. The food industry will be propelled to a new level as a much more knowledge-based enterprise. In many respects, the information content of the food industry will exceed that of other life science industries. The challenge to food is more complex than simply providing health.

Providing healthy diets is relatively easy. Scientists have optimised diets for a wide variety of agricultural models from the lactating dairy cow to the broiler chicken (Guevera 2004; Tedeschi et al 2000). The problem is, neither cows nor chickens have a choice, people do. Providing healthy and delicious foods is the real challenge. Foods are an intimate part of everyone's daily lives, and for centuries the pleasures of foods have defined much of human life's personal delights. During the last generation, immediate, personal choice of foods has become a major added value of the food marketplace (German et al 2005b). Consumers who have increasingly been able to choose from a wide range of foods will not wish to abandon all of the values of taste, flavor, texture, convenience, etc simply for a promise of improved health, nor should they. Food values are designed by what is termed in Boolean algebra as the 'AND' operator. That is, food values do not exist as this value 'or' that value, instead, food values add incrementally. Foods must be simultaneously safe AND delicious AND convenient AND affordable. Thus, if foods with greater personal health are to succeed in the market place, the values of personal health must be added (ANDed) to all of the existing values of the same or similar foods. Food that is healthy for an individual must also be delicious. The potential is that individualising for health will be simultaneously personalised to delicious to that individual. This will mean that foods of the personalised future must be able to maintain existing extrinsic values while at the same time altering their composition to match specific intrinsic health goals. Is this possible? Of course, reformulating existing foods to the metabolic needs of individual consumers is an old idea. In some cases a very, very old idea.

The food industry has assembled considerable information about the composition, structures and physical properties of edible agricultural commodities, the biochemistry of these biological systems and the principles of process engineering of biomaterials necessary to formulate, assemble and distribute foods. The focus of much of the food industry's research and development over the past century has been to manipulate specific food properties or 'functionalities' while maintaining flexible control over the basic food compositions. This trend in research and application has been driven by various factors, including cost, safety, ingredient availability and, increasingly, health. An example is the value of sweetness. Sweetness was a major driver of food technology development starting centuries ago with

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the crystallisation of natural sugars (sucrose) from sugar cane, to production of intensely sweet sugars (fructose) by enzymatic hydrolysis and isomerisation of starches, to the discovery and chemical synthesis of intensely sweet, non-caloric sweeteners (aspartame). The latter sweetener has obvious value to diabetics for whom the routine consumption of sugar can be deleterious to their health. Another example is the shortening properties of plastic fats. The functionality of 'shortening' as an explicit food ingredient began with the rendering or creaming of animal fats, was broadened industrially with the hydrogenation of refined vegetable oils and is now being extended agriculturally by selective breeding of plants to modify the fatty acid composition of seed oils (Flickinger 2007).

Process engineering has also dramatically increased our abilities to manipulate various ingredient compositions into specific desired physical properties of final foods. Traditional frozen dairy dessert (ice cream) is one of our most delightful foods. Ice creams were co-invented at various points in culinary history taking marvelous process advantage by simultaneously joining cream-based foams with the phase changes of water and fat to form stabilising crystals. Newer processing technologies take advantage of extrusion and gas injection to produce frozen foams with widely varying compositions, nevertheless achieving the similar desired (and delightful) physical properties (Windhab and Wildmoser 2002). An even more flamboyant example of the ability of food process design to produce a desired result is that of imitation caviar. Judicious understanding of the gelling properties of proteins in mixed hydrocolloid suspensions and simple flavoring techniques led to the production of one of cuisine's most expensive items using simple, inexpensive raw materials (Tolstogustov 1986). The number of food products whose organoleptic properties are achievable with a wide range of final compositions of macromolecules is very wide. All of these food products illustrate the scientific knowledge that the food industry has amassed to manipulate food composition widely while achieving product properties that are recognisable as delightful foods by discerning consumers. This level of understanding of the chemical and biochemical events that underlie food processing has provided the knowledge base necessary to begin personalising food that are both simultaneously healthy *and* delightful.

EDUCATION

The scientific and technological innovations necessary to achieve a more personalised diet and health system are being assembled. Yet there is a more critical aspect of such a future that must be added: education. The public education system has abandoned one of its key mandates, to educate the public about personal health. The relative state of knowledge of the population for all issues related to diet and health is nothing short of deplorable. The fundamental ignorance of the population has two distinct indications. First, uneducated consumers are unable to make informed decisions about their own health management including food choices and lifestyle behaviours and as a result a large fraction of the population is suffering from health problems caused by inappropriate diets. Examples of the poor decision making include the consumption of significant fractions of daily calories as sweetened, carbonated beverages, simple sweetened starch confections or deep fried starch products (Bertéus et al 2005). Simple educational interventions have shown dramatic improvements in product choices indicating that the problem can be addressed in part by educational solutions (Matvienko 2007). Second, consumers are unable to recognise sound relationships between biology and food and as a result much of the public scrutiny over the agricultural process is being directed in illogical and unsustainable directions. For example the widespread and growing enthusiasm for raw food and 'natural' plant materials as being unusually and uniquely healthful is fanciful and in many cases nutritionally inadequate (Hobbs 2005). On a broader scale, the avoidance of process technologies for food safety and the use of staple agricultural commodities to produce transportation fuels has both immediate and long term implications to the health of populations and the sustainability of agriculture itself.

It is now time to establish a very different kind of health education in the school system personal health education. Teachers will need to be trained in how to teach health from a personal and actionable perspective. The curriculum will need to take advantage of various health assessment technologies to provide the data input to the process. One can imagine straightforward imaging technologies being instrumental in providing students with the basic personal health environment and more specific metabolic, physiologic and immunologic measures being part of the assessment and curriculum development.

CONCLUSION

Food is not only a source of nutrients, but also the chemicals and structures that provide the substrates, fuels and intestinal dynamics that guide our metabolic health. The disturbing increase in diet-related diseases in the world-wide human population attests to the failure of modern diets to deliver enhanced health to the entire population. The rise in diet dependent diseases is also testament to the inability of all humans to match food choices to their overall nutritional needs in all environments and lifestyles. The diversity of human genetics and lifestyles implies that the same diets will not fit all individuals equally well. Some degree of personalisation of foods and diets would seem to be inevitable, much as much of our lives are being enriched by personalised consumer goods from shoes to automobiles. Yet each of these product classes requires knowledge of the performance needs of the consumer and knowledge of the product performance attributes by the producer. Foods will not be different. Consumers desperately need to take charge of their education of personal health. As they do, the food industry must be in a position to deliver individual health values to them.

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