Dietary diversity, global change, and human health

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Plant biodiversity is essential to human health. Plants provide sources of both nutrients and medicinal agents, form components of robust ecosystems and contribute to sociocultural well-being. Traditional values and scientific conceptions concur on the necessity of dietary diversity, particularly of fruits and vegetables, for health. In the face of economic and environmental changes, increased simplification of the diets of large numbers of people to a limited number of high-energy foods presents unprecedented obstacles to health. Cultural knowledge of the properties of plants erodes at the same time. Conservation of biodiversity and the knowledge of its use, therefore, preserves the adaptive lessons of the past and provides the necessary resources for present and future health.

Figure 1 depicts a model of the relationships among biodiversity, diet and health in the context of contemporary global environmental and socioeconomic change, and provides a framework for discussion of the implications for human welfare.

Dietary Diversity and Health

A handful of epidemiological studies uphold the conventional wisdom embodied in dietary guidelines concerning the benefits of a varied diet (Tucker 2001). For example, in a study of 42,254 American women (mean age, 61 years) those who consumed a greater number of recommended foods had a decreased risk of mortality (Kant et al. 2000). Women in the highest quartile (median variety scores of 15) had an odds ratio of dieing in a five and a half year period of 0.69 in comparison to the lowest quartile (variety score of 7). The association of dietary diversity to longevity and reduced rates of chronic degenerative diseases such as cardiovascular disease, diabetes and cancer for men and women was shown in previous work of Kant et al. (1995).

In an Italian study, dietary diversity, most strongly in vegetables and fruits, was associated with reduced incidence of stomach cancer (Le Vecchia et al . 1997). This coincides with the recognized relationship of the benefits of Mediterranean diets in the reduction of risk for chronic degenerative diseases to fruit and vegetable consumption. Similarly, Drewnowski et al (1996) show that while French diets are higher in fats than

those in the USA, and therefore lower on indices of dietary quality, overall diversity likely accounts for their recognized benefits.

Fewer data exist to support the contribution of dietary diversity to health in developing countries. However, dietary diversity has been linked to improved anthropometry in children 1-3 years in Kenya (Onyango et al 1998). In Mali, Hatløy et al. (1998) demonstrated a strong correlation of diversity of fruits and vegetables with overall nutrient adequacy and with specific nutrients such as vitamins A and C.

Among different studies inconsistent measurement of diversity by indices of the number of individual foods as well as numbers of quality foods makes comparisons and general conclusions difficult. Key to future work in this area is development of common methodologies for measuring dietary diversity. Nonetheless, the suggestion that diversity in fruits and vegetables contributes to nutrition and health is consistently supported.

Food Functionality in Relation to Dietary Diversity

Dietary quality as it contributes to the health benefits of dietary variety can be associated partly, but by no means exclusively, with nutrient content. Nutritional quality of the diet does improve with consumption of greater food diversity (Shimbo et al 1994; Hatoly et al 1998; Slattery et al 1997). However, content of vitamins, minerals, protein and energy alone do not explain the benefits associated with the Mediterranean or other diets. Variety in non-nutrients such as phytochemicals and fiber, as well as in types of fat and carbohydrate, also plays an important role.

Such scientific insights have stimulated attention to so-called functional foods, more so in developing countries where both consumer demand and entrepreneurial initiative drive interest. Japan through its licensing of FOSHU (Foods of Specific Health use) foods starting in 1991 and the United States by the Food and Drug Administration acceptance of health claims under the NLEA Act of 1990 provide sanction and impetus for recognition of the functions of food to health beyond their contribution to basic nutrition. In parallel many of the dietary supplements and natural health products sold in dosage form, for example garlic and grape seed, are targeted to diseases and conditions associated with diet. Such products derive both from conventional foods and from herbal sources, and together represent the growing profusion of plant diversity ingested by consumers in developed countries.

Many of these products have longstanding traditional reputations and use in various part of the world. Relevant food and beverage-derived entities include soy, tea, tomato, species of *Vaccinium* (cranberry, bilberry and blueberry), maca (*Lepidium meyenii*) (Johns 1981; Quiros and Aliagas-Cardenas 1997) and *Opuntia ficus-indica,* as well as fish oil and other marine foods.

Global Change, Diet and Health

Rapid processes of change in both industrialized and developing countries that profoundly alter relationships between humans and the ecosystems in which they live have dietary implications. Traditional subsistence systems often represent finely-tuned and unique human-resource interactions that ensure nutritional needs are met. Disruption in environmental integrity in turn affects patterns of human health, disease and nutritional status (Johns and Eyzaguirre 2000). Dietary inadequacy, including loss of diversity, represents a key outcome of change as it directly precipitates challenges to human health.

Among the major environmental disturbances affecting humans are population growth, ecosystem destruction associated with industrial, commercial and agricultural development, climate change, urbanization and loss of biological resources. As the latter is simultaneously affected by other disturbances and the basis for human food systems it plays a central role both in terms of dietary change and to potential solutions (Figure 1). Degradation of the diet coupled with environmental stresses challenges the health of human communities in unprecedented ways including through malnutrition, immunity and infection, environmental toxicants and oxidative stress.

Malnutrition. Overpopulation and factors leading to ecosystem and biodiversity destruction that undermine the capacity to produce food result in inadequate intake and/or consumption of nutritionally poor foods, and consequently protein-energy malnutrition (PEM). Famine in many cases has anthropogenic causes. Micronutrient malnutrition may reflect a disruption of traditional patterns of subsistence resulting in reduced access to and intake of crucial biological resources. So-called diseases of affluence such as diabetes and coronary heart disease also represent disruptions of human-environmental relationships. Traditional subsistence patterns couple energy expenditure for food procurement and other activities with intake of foods with low energy density. In addition to energy over-consumption, in diets of industrial societies increased reliance on processed foods may affect health by reducing intake of nutrient and non-nutrients that protect health more subtly (Johns, 1999).

Immunity and Infection. Disease factors of environmental origin compromise nutritional status that in turn plays a critical role in the severity and prevalence of illnesses. Disruption of natural ecosystems can elevate rates of infectious disease by increasing exposure to vector-borne disease such as malaria, leishmaniasis, or dengue (Spielman and James, 1990), or through impacts on density related factors such as sanitation and direct person to person transmission. Major public health problems of global importance such as tuberculosis, gastrointestinal diseases, measles and respiratory disease all reflect the interaction of nutritional and environmental factors (Platt, 1996). Malnutrition may result in micro-nutrient deficiencies such as vitamin A and iron that affect the immune system and compound these and other diseases (Tompkin, 2000).

Toxicants and Xenobiotics. Environmental contamination from industrial and agricultural chemicals such as heavy metals, organochlorines and radionuclides compromise nutritional status and health (Kuhnlein and Chan, 2000) and have both local and global impacts on diet and nutrition. Apart from the toxicological consequences of direct exposure, local contamination may reduce the dietary options of local populations. Herbaceous plants that grow as weeds in fields or along margins and are consumed as pot herbs and relishes provide traditionally important supplements and sources of micronutrients for many people (Price, 1997). Herbicides, fungicides and insecticides may eliminate these or make them unfit for consumption. Additionally, environmental and subsistence changes may increase exposure to naturally-occurring toxicants such as aflatoxins. Cancers can be attributed to contaminants, and fear of exposure can lead people to abandon components of their traditional food systems.

The consequences of persistent organic pollutants (POPS) that are transported in the atmosphere are felt on traditional food systems far removed from major sites of pesticide use (Kuhnlein and Chan, 2000). Northern populations who rely on hunting and fish are particularly vulnerable to these disruptions. Unfortunately, dietary alternatives based on market foods in remote communities are expensive and usually of lower nutritional quality.

Oxidative Status plays an important role in many disease states, including chronic diseases such as diabetes, cardiovascular disease and cancer, both as a causal factor and an adverse outcome. Within the model of environmental change and health in Figure 1, environmental toxicants represent serious contributors to oxidative stress. Exogenous antioxidants, particularly dietary vitamins and non-nutrients, form a key component of the normal defense against oxidative stress, and reduction in plant dietary diversity therefore has further negative consequences.

Urbanization and the Dietary Transition

Urban populations make increasing impacts on the environment through market demands, by settling in natural and agricultural areas, and through pollution associated with industrial growth and urban waste. In this situation the urban poor are doubly affected by deficiencies in diet and by the negative consequences of living in unhealthful conditions.

Urbanization and socioeconomic changes in developing countries are characterized by diets higher in energy, including vegetable oils and other fats heated under oxidizing conditions, and lower in diversity in fruits and vegetables than those of rural populations. As a consequence, within the coming decades the rates of obesity, diabetes, cardiovascular disease and cancer can be expected to follow the epidemic trends already seen in Latin America (Albala et al. 2001; Uauy et al. 2001) and elsewhere (Popkin et al. 2001).

In Africa for large segments of the population these conditions are likely to co-exist with classic nutrient deficiencies and with infectious disease. With urbanization in sub-Saharan Africa projected by the United Nations Centre for Human Settlements (UNCHS-Habitat) at 4% per annum over the next 15 years and to reach greater than 50% of the population of the region, solutions to forestall the nutrition and health impact of this trend are acutely needed. Here and globally greater use of plant biodiversity based on scientific evaluation of plant properties, cultural support programs, dietary education, innovative processing, and marketing provide possible avenues for mediating the impacts of change.

The Importance of Crop Diversity and Neglected and Underutilized Species.

Erosion of food crop diversity

Whereas over seven thousand plant species have been traditionally used for food, three species – rice, wheat and maize – account for sixty percent of the total caloric intake in the human diet (Eyzaguirre et al 1999). Global modern agriculture typically focuses on yields of a few crops and years of genetic engineering have brought about high yielding, pest- and drought-resistant varieties of a small number of distinct food species. The sheer magnitude of agricultural effort applied to the three principal crops has led to a decline in the consumption of more diverse grains. There has been an accompanying decrease in the variety of vegetable and fruit species consumed. Cultural change and urbanization compound this trend (Chweya and Eyzaguirre, 1999). Additionally, many traditional foods are now associated with being poor or backward. The result is disruption of dietary patterns and loss of dietary diversity. Little is known about the impact of these dietary changes on human nutrition and health.

Neglected and Underutilized Species (NUSs)

However, following the well-support principles of dietary diversity, a variety of foods undoubtedly contribute to a balanced diet in local communities. In Africa, for example, NUSs of local dietary importance include cereal grain crops like fonio (*Digitaria exilis*), roots and tubers such as yams, pulses and oil seeds such as bambara groundnut (*Vigna subterranea*) (Heller et al. 1997), leafy vegetables (Chweya and Eyzaguire 1999) and tropical fruits such as African plum *(Dacryodes edulis)* or the bush mango (*Irvingia gabonensis*).

While the importance of diversity and the wisdom inherent in the traditional systems that incorporate NUSs can be appreciated even without knowing the specific nutrient constituents of the individual components of the diet, existing data on a few species provide useful insights into the way they contribute to health. For example, baobab (*Adansonia digitata*), for which young leaves and the fruits are eaten, has local dietary importance in several African countries. The dried fruit pulp is added to porridge, made into sauces and added directly to cooked dishes. Not only rich in calcium (285 mg/100g edible portion), it has both high amounts of iron (7.4 mg/100g) and vitamin C (270

mg/100g) (West et al. 1988) that combined should interact to increase iron absorbability and prevent anemia Even without comprehensive studies we know that leafy vegetables in general make important contributions in provitamin A, vitamin C, folate, iron, calcium, fibre and protein (West et al 1988, Chweya and Eyzaguirre 1999; Uiso and Johns 1996), recent controversies regarding the bioavailability of provitamin A notwithstanding (de Pee et al 1998; Solomons and Bulux 1997).

Functional Diversity in a Developing Country Context

Traditional concepts of diet may include associations with health. Generally speaking these do not refer to nutrients but to specific functional properties. Some traditional attributes such as tonics or strengtheners may be understandable in nutritional terms. Other concepts of food-derived benefits relate to physiological and pharmacological properties and can be supported by scientific investigations in these areas.

Many of the benefits of non-nutrients may in fact exceed those attributable to nutrients. For example, vegetable diets that make modest contributions to improving vitamin A status result in significant increases in serum levels of lutein (de Pee et al 1998), an antioxidant for which protective benefits in relation to ocular disease (Brown et al 1999; Sommerburg et al 1998), as well as cardiovascular disease and cancer, are increasingly recognized. In this light the over-attention on the limitations of leafy vegetables as sources of provitamin A (de Pee et al 1998; Solomons and Bulux 1997) seems somewhat myopic.

Potential health-related functions of dietary plants include antibiosis, immunostimulation, nervous system action, detoxification, anti-inflammatory, anti-gout, antioxidant, glycemic and hypolipidemic properties

Ethnobotanical and analytical work of my group among many others has addressed a number of these activities. For example, among leafy vegetables attributed action against disturbances of the gastrointestinal tract by the Luo of western Kenya and Tanzania, the leafy vegetable *Solanum nigrum* has strong activity against the protozoan parasite *Giardia lamblia* (Johns et al. 1995). Additionally we have reported on i) the antioxidant activity of phenolics (Lindhorst 1998) and cholesterol-binding activity of saponins (Chapman et al 1997; Johns et al 1999) in roots and barks that the pastoral Maasai add to fatty soups and milk, ii) the potential hypolipidemic activity of gums chewed by the Maasai (Johns et al. 2000), as well as iii) antioxidant activity of Tibetan treatments of heart disease (Owen 2000) and iv) anti-diabetic remedies of Indigenous peoples of the boreal forests of eastern North America (McCune 2000). From the latter region we have also identified xanthine oxidase activity in traditional remedies for gout and related symptoms (Owen and Johns 1999), as well as in dietary additives of the Maasai (unpublished results).

Potential immunostimulation of the plants in Maasai and other dietary systems offers a promising direction of future research that has important implications in relation to

HIV/AIDS. Hypoglycemic properties know from many plants used in traditional medicine and diet such as *Opuntia* spp. or bitter gourd *Momordica charantia* (Marles and Farnsworth 1995; Johns and Chapman 1995) offer an important direction of investigation in relation to diabetes and other aspects of the dietary transition.

Such functional activities can be attributable to phytochemical constituents of these plants. Diversity of function and of chemical composition, then, add further dimensions to the diversity inherent in the food and medicinal plants used around the world.

Notwithstanding the potential for income generation that comes with the commercialization of some traditional foods and medicinal products, functionality generally speaking has a different significance in addressing the needs of the majority of the populations in developing countries than it does in Europe, North America or Japan. Whether for rural subsistence or in the diets of urban populations, function of culturally-significant species has immediate biological and social importance to the health of people in developing countries.

Dietary Adaptation and Optimization

Rational use of dietary resources and application of knowledge concerning their value offer a course for optimal adaptation (Figure 1) to the changes facing populations around the world (Johns and Eyzaguirre 2002). Considering the magnitude and unprecedented nature of the shifts occurring in lifestyle, scientific insights into the relationships among environment, diet and health and the adverse consequence of current change, as well as scientific evaluation of the properties of plant and animal foods, would seem essential tools for obtaining novel solutions for contemporary problems. In this process of adaptation, however, the lessons of the past represented by the wealth of indigenous knowledge of biological resources and ecosystems, as well as the diversity of resources themselves, are essential to a process of adaptation. In this regard documentation and study of the world's biocultural diversity should take high priority.

Conclusions

The diversity of plant resources plays an essential role for enabling populations to meet their nutritional, health and socio-cultural needs. Biodiversity equates with dietary diversity which equates with health. As it embodies biological, psychological, social and ecological well-being the health that should be sought for all the world's people is much more than simply the absence of disease. In the contemporary world where global change impacts traditional ecology in ways that threaten biodiversity and at the same time undermine human subsistence, such health is a vital rationale for managing biodiversity.

Plant resources coupled with the biocultural wisdom inherent in traditional systems can make important contributions to address the serious problems of food insecurity and under-nutrition facing developing countries; at the same time plant biodiversity is an

essential resource as societies adapt to current changes, particularly those associated with urbanization. In this regard, rural – urban linkages are crucially important. The diverse nutrition and health functions that plants serve in traditional culture, and indigenous knowledge of plant diversity, offer potentially valuable solutions that enable biodiversity to address the unique problems facing contemporary society.

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Figure 1: Model of Biodiversity, Diet and Health in the Context of Global Change