Ways food systems undermine choice to the detriment of herbivores and humans

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Abstract

Landscapes with rich arrays of forages and foodscapes with rich assortments of wholesome foods are nutrition centres and pharmacies for herbivores and humans. Whether herbivore or human, health ensues when cultures learn to combine biochemically rich foods into meals that nourish and satiate. Biochemically rich diets include not only energy, protein, minerals, and vitamins, but also a host of other compounds—such as phenolics, terpenes, and alkaloids—with nutritional, prophylactic, and therapeutic benefits. We discuss some not-so-obvious ways food systems undermine biochemically rich alternatives and choices to the detriment of herbivores and humans. We also consider how food systems can enable individuality in form (morphology), function (physiology), and behavior by providing biochemically rich foods. We conclude by discussing how providing a variety of wholesome foods—and letting the wisdom of the body guide food selection—can enhance the health and well-being of herbivores and humans.

Keywords: livestock; human; diet; health

Introduction

In this manuscript, we review findings from different disciplines to illustrate how food systems can affect choice in herbivores and humans. We do so to stimulate thinking, dialogue, and discussion we hope will lead to innovative research that links palatability with food selection, nutrition, and health. Palates link animals with landscapes through flavour feedback associations; availability of biochemically rich foods; and learning in utero and early in life to eat nourishing combinations of foods (Provenza et al. 2015). Flavour-feedback associations are how cells and organ systems, including the microbiome, communicate with the palate to meet needs for nutrients. Those needs are best met through biochemically rich diets, which are etiologic in health (Jacobs & Tapsell 2007). Biochemically rich diets include not only energy, protein, minerals, and vitamins, but also a host of other compounds—such as phenolics, terpenes, and alkaloids—with nutritional, prophylactic, and therapeutic benefits (Provenza et al. 2015; 2018). The availability of biochemically rich foods depends on ecological features of a landscape and how herbivore and human cultures learn to combine those foods into meals that nourish and satiate. Providing an array of biochemically diverse foods enables individuality in form (morphology), function (physiology), and behaviour, which arises from interactions between genes and environments.

Individuality

Nobody who works with livestock questions the striking variation in how they behave. Differences in form, function, and behavior are apparent for breed, sex, and age of animal. Within these categories, however, no two individuals react in the same way to a challenge—from changes in management to selecting a diet while foraging in confinement or on pastures. While individuality has been the foundation for disciplines such as ecology, evolutionary biology, ethology, and animal welfare, the view of individual variation as a nuisance has led researchers who study animal production to overlook implications for management that could enhance the welfare of animals and the profitability of farmers and ranchers (Gregorini et al. 2017).

In *Biochemical Individuality*, a treatise first published in 1956, Roger Williams discusses implications of individuality for nutrition and medicine. As he points out, differences in form and function are why forensic experts can identify each person by a thumbprint. Differences in function are why a bloodhound can track individuals by our odours. If we could look at our insides, we would be astonished at the differences. Stomachs vary in size and shape as much as our ears, noses, and mouths. Stomachs also vary in function. A Mayo Foundation study of 5,000 people with no known stomach ailments showed they varied a thousand fold in pepsin and hydrochloric-acid content. People also vary greatly in the many hormones that influence emotions, appetite, and food intake. Such differences help explain why we tend not to eat with equal frequency or in equal amounts, nor do we choose the same foods.

As documented extensively by Williams, people differ in needs. On sea voyages without fresh fruit, only certain individuals developed scurvy. In populations that eat mainly polished rice, only certain individuals develop beriberi. In some areas of the U.S.A. when the diet was poor, chiefly among those with low income, only certain individuals develop pellagra. Not all children with limited access to sunlight develop rickets. The amount of vitamin D required by the ‘average’ child is estimated to be 400 units daily, but the daily amount required to prevent rickets in more susceptible children may be 5,000 to 10,000 units or even greater.

Williams highlights great variation in food selection when animals—young rats, mice, hamsters, and baby chicks—are allowed to select their diets: meat four-fold, butter seven-fold, carrots four-fold, sugar seventeen-fold, salt four-fold, yeast forty-six-fold. That is also the case for people. In a study of 19 healthy men, needs for calcium varied from 222 to 1,018 mg/day. The same was true for vitamins A and C. He concludes by noting many reasons why he has difficulty escaping the conclusion that animals make different choices at least in part because they have different needs. That conclusion is supported by empirical studies where sheep, cattle, and humans are provided with different choices (Davis 1928, 1939; Atwood et al. 2001, 2006), and modelling efforts that build on those observations (Gregorini et al. 2015).

Differences in form and function, illustrated in the behaviour of livestock, occur for intake of primary and secondary compounds. For example, although they all grow well, sheep of uniform sex, age, and breed vary greatly in the proportions of roughages and grains they eat in confinement (Scott & Provenza 1999). While most goats avoid eating current season's twigs of the shrub blackbrush, due to their high levels of tannins, 10% to 20% of goats prefer them (Provenza et al. 1990). Likewise, cattle differ more within than among breeds in tolerance of toxic alkaloids in larkspur with implications for developing herds that can use rangelands that are otherwise off-limits at certain times during summer (Welch et al. 2012; Green et al. 2014).

Finally, Williams discusses the implications of individuality for medicine and nutrition. Regarding the former, he anticipated correctly, over 50 years ago, that treatments will ultimately need to be tailored specifically to individuals, as no two people are alike. Concerning the latter, he noted the significance of "body wisdoms" and concluded: "If this wisdom were universally possessed by all members of the human family, there would be no need to study nutrition and the only deficiency diseases would be those induced when suitable foods were not available."

Choice enables individuality

To enable individuality and enhance nutrition, production, health, and welfare of livestock in many areas of France, skilled herders design grazing circuits to enhance choice, to increase appetite and intake by creating synergies among meal phases, and to increase intake of abundant but less palatable forages (Meuret & Provenza 2014, 2015). To do so, they partition landscapes into grazing sectors that are carefully sequenced within daily circuits. Meals are based on complementarity blends of terrain and plant communities within and among sectors. Herders identify and ration various sectors into phases of a meal: appetite stimulator or moderator, first course, booster, second course, and dessert sectors. Allowing animals to choose among different forages within and among sectors, and presenting them with diverse forages from meal-to-meal, stimulates appetite and enables individuality, which enhances production, health and welfare. Based on this work, Gregorini et al. (2017) developed a framework for designing feeding circuits and menus for dairy cows under intensive pastoral systems.

Lambs offered a variety of different foods eat more and have less stress, as reflected in cortisol levels and neutrophil to lymphocyte ratios (Catanese et al. 2013). Lambs fed a ration in different flavours have more even intake of food from day to day, thus they eat more and tend to grow faster than animals fed the ration in a single flavour (Villalba et al. 2011a,b). Flavour diversity also changes profiles of hormones such as CCK and GLP-1 involved in food intake regulation, likely due to changes in feeding patterns. Flavour diversity also enhances lambs' acceptance of and preference for novel foods (Villalba et al. 2011a,b; Catanese et al. 2012).

The same concepts apply to providing supplemental mineral on rangelands. Variation in mineral content among different pastures and in needs among individuals is why some ranchers offer cafeteria mineral supplements (Provenza &Villalba 2006). Sheep are able to self-select to meet needs for minerals such as P, Ca, and Na (Villalba et al. 2008). These findings support the practice of offering individual minerals free-choice so animals can select the particular mineral(s) that are low in the forages they are consuming (Holliday & Helfter 2014).

Implications of choice for herbivores and humans

The goal of many nutritionists is to increase food intake by livestock, assuming greater intake equals greater nutrient supply, and thus better production. To do so, animals confined in feedlots and dairies are fed total-mixed rations (TMRs), while livestock on pastures are often forced to graze monotonous swards free of "anti-nutritional" plant secondary compounds. People involved in the feedlot industry and high-intensity grazing successfully feed millions of animals on TMRs and monotonous swards, but these practices may reduce efficiency and increase costs.

Rather than allow animals to choose among ingredients, nutritionists feed TMRs and monotonous swards in part because they are afraid animals will get sick from eating too much grain or eat less of plants with 'anti-nutritional' compounds, presuming animals are unable to balance their own rations. What would happen to food intake and production, and the cost for food, if animals could formulate their own rations from concentrates and forages? Conventional wisdom says animals will eat too much grain, get sick, eat less and perform poorly because they are unable to balance their own rations by wise use of different plants. Costs would be high.

Yet, when cattle and sheep are offered roughages and grain, they seldom eat too much grain if they are allowed to gradually increase intake of grain. When offered alfalfa pellets and rolled barley, the 'average' lamb eats 55 percent grain and 45 percent alfalfa, but individuals vary along a continuum from lambs who eat virtually no barley to lambs who eat twice as much barley as alfalfa (Scott & Provenza 1999). The 'average' lamb eats much less grain than animals fed a TMR designed to maximize weight gain. When they can choose, calves and lambs balance intake of grain and roughages to prevent acidosis and they learn to select combinations of foods that best meet their needs for energy and protein (Scott & Provenza 1999; Atwood et al. 2006).

Over-ingesting grain causes acidosis, experienced as nausea, which reduces food intake and causes food aversions in livestock (Provenza et al. 1994). Forced to eat high-grain diets, sheep and cattle self-medicate on bentonite and sodium bicarbonate to alleviate acidosis (Phy & Provenza 1998ab; Villalba et al. 2006). Lambs and cows foraging on fodder beet crops alleviate acidosis by increasing intake of hay when available (Waghorn et al. 2018). Combinations of foods that meet nutritional needs lead to satiety and feelings of well-being, whereas post-ingestive excesses (acids or ammonia) and deficits can lead to feelings of discomfort, malaise, nausea, and aversions that lead to cyclic patterns of intake (Forbes & Provenza 2000), illustrated mathematically with the MINDY model (Gregorini et al. 2015).

Cattle Studies

When they are fed a high-energy ration low in protein relative to their needs, livestock will over-ingest energy to meet needs for protein (Webster 1993; Provenza and Villalba 2006). Thus, a TMR formulated for the 'average' individual will exceed the needs of some animals and not meet the needs of others, even in uniform groups of animals. To compensate, individuals eat more (incidental augmentation) or less (incidental restriction) of the TMR. Food intake may actually *decrease* if animals are allowed to self-select their own diets, thereby increasing performance while enhancing animal health and welfare while foraging in feedlots or on monoculture (or simple mixture) swards (Gregorini et al. 2017).

That was shown in a two-month study where calves allowed to choose among rolled barley, rolled corn, corn silage, and alfalfa hay ate *less* food but gained weight at the same rate as calves fed a TMR made by grinding and mixing the four foods in proportions formulated to meet the nutritional needs of the 'average' animal (Atwood et al. 2001). Food selection varied among individuals offered a choice of the four ingredients throughout the study. No two individuals ever selected the same diet, nor did they select a diet similar in proportions to the TMR, and no animal consistently chose the same foods from day to day. However, because animals offered a choice ate less, the daily cost per unit of weight gain was 24% less for choice than for TMR.

Bison Studies

In the U.S.A., male bison are typically weaned and placed in feedlots when they would be moving from extended families into bachelor groups. Levels of stress are higher for male bison placed in confinement compared with free-ranging bison. Providing adequate space, offering a choice of foods, and leaving young bison on pasture prior to slaughter lowers stress, costs of gain, and illness (Shaw 2012). These effects were illustrated in a long-term, ranch-scale study where bison were fed a total-mixed ration in tight confinement, offered a choice of feeds in loose confinement, or foraged on rangelands where they were also offered a choice of grains. While the loose-confinement group had higher average daily gains than the other groups, the rangeland group provided the highest net returns (Burritt et al. 2013).

Collectively, the studies of cattle and bison suggest individuals can more efficiently meet their needs for nutrients when offered a choice among dietary ingredients and flavours, rather than constrained to a single diet nutritionally balanced for the 'average' animal. Transient food aversions, from eating the same food repeatedly, further compound the inefficiency of a single mixed ration. Feeding practices that allow animals to choose enable producers to efficiently capitalize on the agency of animals, thus reducing illness and improving performance. That is true not only for cattle, sheep, and bison in confinement, but also when herbivores are foraging on monocultures as opposed to diverse mixes of plants on grasslands and rangelands.

Protein-Leverage Hypothesis for Humans

Human food systems based on *food quantity* and *energy density*, rather than on *biochemical richness*, have a maladaptive feedback loop built into them. The more energy-dense, but biochemically poor, foods a human eats, the more a person needs to eat, in a quest to obtain nutrients such as protein and minerals present in low concentrations (Simpson & Raubenheimer 2006; Garcia et al. 2009). Differences in flavors of energy-dense processed foods are distinct enough to give consumers a sense of variety, which stimulates intake, despite the nutritional sameness that leads to overeating (Remick et al. 2009).

While most emphasis to control obesity has been on reducing intake of carbohydrates and fats, the role of protein has been ignored. Yet, when people eat a diet that contains a lower ratio of protein to energy than they require, they will over-ingest energy to meet needs for protein (Booth & Thibault 2000; de Castro 2000). Protein intake, which makes up only about 15 percent of dietary energy intake, has remained nearly constant in populations during the development of the obesity epidemic. Thus, some researchers argue that has given protein the leverage to contribute to the obesity crisis (Simpson & Raubenheimer 2006). People can moderate these effects by eating high-quality sources of protein and less energy-dense foods.

Nutritional state affects choices

Scientists who study food choices of herbivores control for nutritional state because excesses or deficits of nutrients alter food selection (Provenza et al. 2015). For instance, if sheep eat an appetizer high in energy, their preference for energy declines while their preference for food high in protein increases; the opposite is true for protein and energy (Villalba & Provenza 1999). Likewise, dairy cattle fed concentrates high in protein while they are in the barn during milking prefer to eat grass (lower in protein) rather than clover (high in protein)—and they eat the less protein-rich parts of the grass—when they then forage on pasture (Emmick 2007; Gregorini et al. 2015). The same is true for minerals. Sheep avoid eating foods high in phosphorus, calcium, sodium, or sulfur when their needs for those minerals are met, but they select foods that rectify deficits when they are lacking those minerals (Hills et al. 1999; Villalba et al. 2008). When lambs have access to salt blocks, they avoid foods with even small amounts of sodium, which is why providing salt blocks on salt-desert shrub rangelands can cause livestock to avoid eating plants like saltbrush that contain sodium (Villalba & Provenza 1996).

Herbivores also satiate on secondary compounds, as illustrated when sheep are first given a supplemental capsule of saponins, alkaloids, or tannins, and then allowed to choose among plots of lucerne, birdsfoot trefoil, and tall fescue (Villalba et al. 2011). Sheep first given a supplemental capsule of saponins and then put on pasture eat less lucerne (high in saponins) and more trefoil (high in tannins) and fescue (high in alkaloids). Conversely, sheep first given a supplemental capsule with alkaloids subsequently eat less tall fescue and more lucerne and trefoil on pasture. Sheep given tannins eat less trefoil and more fescue and lucerne.

Not unlike findings for supplemental nutrients, animals are more inclined to self-medicate when they are not provided with anti-parasitic drugs. Goats infected with internal parasites eat more tannin-containing heather than do goats treated with anthelmintic drugs that kill internal parasites (Osoro et al. 2007). Parasitized goats selectively browse *Albizia anthelmintica,* which decreases faecal egg counts. Sheep with parasites eat more tannin-containing food than do non-parasitized sheep, and parasitized sheep reduce their intake of high-tannin food when their parasite infection is terminated with ivermectin, a drug that kills internal parasites (Lisonbee et al. 2009ab; Villalba et al 2010; Villalba et al. 2013). Likewise, sheep infected with *Haemonchus contortus* eat more tannin-rich *Lysiloma latisiliquum* than non-infected animals (Martinez-Ortiz-de-Montellano et al. 2010). As parasite loads escalate, sheep increase their intake of plants with tannins, which in turn decreases faecal egg counts.

For many humans, the relationship between nutritional state and the availability of foods differs from when our ancestors hunted and gathered (Armelagos et al. 2011). Humans have ready access to energy-dense processed foods that are altered by reducing or removing existing nutrients and enriching or fortifying with other nutrients (Tremblay & Arguin 2013). People also take supplements. In the U.S.A., 40% to 50% of the men and women 50 years of age or older regularly use multivitamin/mineral supplements, with annual sales of over $11 billion. In New Zealand, 59% of adults take at least one supplement, the most common being multivitamins and minerals followed by fish oil (Parnell et al. 2006). Many people feel supplements are important for maintaining good health, but they also report a large degree of confusion regarding which supplements they should take. Indeed, large-scale randomized trials show no benefit from taking supplements for the majority of the population, and some studies show increased risk of cancers from taking certain vitamins (Kamangar & Emadi 2012).

If humans respond to excesses as do herbivores, creating energy-dense foods, fortifying and enriching those foods, and taking supplemental nutrients may cause us to avoid eating foods such as fruits and vegetables that provide minerals, vitamins, and an array of phytochemicals. Would we want to eat more vegetables and fruits if we weren't ingesting energy-rich fortified and enriched foods and taking supplemental minerals and vitamins?

Peoples' awareness of recommendations to eat fruits and vegetables increased during the last 20 years. In the U.S.A., about 8% of adults reported being aware they should eat at least 5 servings of fruits and vegetables daily in 1991. That number increased to 40% in 2004. While awareness is likely higher today, that has not translated into changes in behaviour (Lee-Kwan et al. 2017). In 2015, just 9% of adults met intake recommendations for vegetables, ranging from 6% in West Virginia to 12% in Alaska. Only 12% of adults met recommendations for fruit, ranging from 7% in West Virginia to 16% in Washington, D.C. Consumption was lower among men, young adults, and adults living in poverty. Among adults, the primary contributor to total fruit intake was whole fruits; among adolescents, it was fruit juices. The largest single contributor to overall fruit intake among adults and adolescents was orange juice. These same patterns are also occurring in countries such as New Zealand (Jury 2008).

Children's responses to sweetened foods and beverages come from sensory systems evolved to detect once more limited calorie-dense foods that taste sweet (Mennella et al. 2016). While this sweet attraction served children well historically, attracting them to mothers' milk and then to energy-rich foods during periods of growth, today it makes them vulnerable to food environments replete with processed foods rich in added sugars. The more added sugar in the diet, the less fruits a child consumes. Once children become accustomed to a highly sweetened diet, foods their sensory systems evolved to eat may no longer taste sweet (Wise et al. 2016).

During the Renaissance, ocean voyages for extended periods without fresh fruits or vegetables led to scurvy. In 1747, a Scottish surgeon in the Royal Navy, James Lind, discovered citrus foods prevented scurvy, though he mistakenly believed scurvy was due to faulty digestion, not vitamin C deficiency (Bartholomew 2002). Sailors gave graphic reports of their cravings and satisfaction when they could eat the foods they craved. Upon making landfall, one British crew gorged on watercress, purslane, sorrel, turnips, and Sicilian radishes. They craved what their bodies needed and they ate plants that met those needs.

Today, those sailors could drink vitamin C-fortified 'fruit' drinks including orange juice made from concentrates. Their scurvy would disappear, along with their cravings for fruits and vegetables (Piernas et al. 2013; Hedrick et al. 2017). Rather than eat a rich array of phytochemicals, however, each sailor would consume a large quantity of the sugar-sweetened calories that have contributed greatly to obesity and diabetes now afflicting people worldwide.

Culture, choices, and Clara's kids

Studies of humans illustrate how flavour-nutrient learning, availability of wholesome foods, and culture can enable health through nutrition. In a six-year study, Clara Davis became the 'mother' of 15 orphaned infants who selected nutritious diets when offered 34 foods of animal and vegetable origins (Davis 1928, 1939). The infants initially sampled all of the foods, and soon developed preferences. No two children ever ate the same foods and no child ever selected the same mix of foods from day-to-day. Davis points out, "Every diet differed from every other diet, 15 different patterns of taste being presented, and not one diet was the predominately cereal-and-milk diet, with smaller supplements of fruit, eggs and meat, that is commonly thought proper for this age." They ate several foods in any meal, and often preferred brains, raw beef, bone jelly, and bone marrow—foods disgusting to 'modern' adults who have not learned to eat them.

Davis suggests their patterns of selection developed due to "sensory experience and doubtless the feeling of comfort and well-being that followed a meal." Selected in appropriate combinations, these foods provided biochemical richness children needed to thrive, though they could have eaten themselves sick even with the healthy assortment of foods she offered. Had one or more selected only meat, fish, and eggs, they would likely have come down with scurvy. Had others eaten only fruits and vegetables, they would have experienced a vitamin B_{12} deficit and megaloblastic anaemia. However, no child ever developed a deficiency. Instead, they selected foods that ameliorated diseases such as rickets, which some of them had when they entered the orphanage. They all grew normally and were healthy, as verified by an attending physician.

Davis argues the key to the children's health was offering them a choice of natural, unprocessed foods that reproduced to a large extent foods eaten by people in many parts of the world with excellent nutrition. Nevertheless, the alternatives available to humans has changed during the past century. Selection for yield and transportability has reduced the phytochemical richness of vegetables and fruits, which adversely affects flavour, nutritive, and nutraceutical value for humans (Provenza 2015). Phytochemically impoverished monocultures or simple mixture swards and feedlot diets can unfavourably affect the health of livestock, and that may adversely affect the richness of flavour, nutritive value, and health benefits of meat and dairy for humans (Provenza et al. 2018). Ironically, as the flavours of produce, meat, and dairy have become blander, biochemically poor processed foods have become more desirable. People in the food industry learned to link feedback from energy-rich compounds with artificial flavours that obscure nutritional sameness and diminish health (Schatzker 2015). Thus, the roles plants and animals once played in nutrition and health have been usurped by artificial foods fortified and enriched in ways that stimulate appetite for processed over wholesome foods.

Davis concludes the results of her studies leave the choice of the foods offered to young children in the hands of their elders where everyone has always known it belongs. However, nowadays the choices people learn to make are mostly under the control of 'elders' in academic, corporate, and political establishments interested more in profits than health. While not always the case, these institutions have inhibited discourse, shaped and skewed the scientific literature, created uncertainty, and influenced government policies to advance dangerous 'food' products (Washburn 2006; Fanelli et al. 2017). The emphasis in science and marketing has enabled some in science, industry, and politics to influence the masses and reap the profits (Nestle 2013).

Those changes are happening globally, as illustrated by the Tswana peoples of the eastern Kalahari. They thrived during a drought from 1965 to 1973, when a drought of similar intensity and timing killed over two million people in the West African Sahel (Grivetti 2006). Tswana peoples lived on wild plants. Tribal elders know over 200 edible wild plants and they use an additional 100-plus species in medicine, magic, construction, thatch, dye, and even as props to teach moral lessons. Sadly, children and young adults express little interest in plant lore, so knowledge of wild plants is not being passed to future generations. Instead, most children are eager to adopt 'Western' cultural behaviours, dress, and fast-food. Yet, as Grivetti points out, a time will come when a drought of severe magnitude will devastate Tswana peoples, for the same reasons it had the peoples in the West African Sahel. Many Tswana will starve in the midst of food plenty, unable to recognize which plants to use for foods and medicines.

That is not to say people in all countries could or should attempt to live on wild plants. Indeed, given current and projected human populations, that is impossible. However, people could change plant selection and farming practices to enhance flavour, phytochemical richness, and health benefits of produce and meat (Brandt et al. 2011; Baranski et al. 2014; Provenza et al. 2018). And people could grow more vegetable, herbal, and medicinal gardens in concert with native plants, rather than attempting to make up for the lack of biochemical richness in our diets by adding artificial agents to enhance the flavour of bland foods. The flavours we crave and the phytochemicals we need would then come from herbs and spices (Sherman & Billing 1999; Tapsell et al. 2006), as opposed to the more than 273 million kilograms of synthetic flavourings Americans now consume annually (Schatzker 2015). Providing biochemically rich wholesome spices, produce, meat, and dairy could change recommendations—from an endless stream of latest advice on what and what not to eat—to letting the 'wisdom body' of each individual guide food selection, as Roger Williams suggested over 50 years ago. For that to be manifest, however, humans will need to create food cultures that offer wholesome alternatives and then let children (and many adults) learn to eat nourishing combinations of foods, as Clara Davis did when she became 'mother' to 15 orphaned infants nearly 100 years ago.

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