PECAN PRODUCTION UNDER A "FOOD SYSTEMS" PARADIGM

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There have been impressive advances in pecan production technologies and strategies over the last century. Progress has been driven as a consequence of societal evolution and its associated forces. This article briefly addresses the possibility the U.S. pecan industry is showing evidence of transitioning to a new paradigm that better fits the needs of an evolving world society. This new paradigm integrates production, sustainability and human nutrition, and will likely require several decades to before it becomes well developed. There is increasing evidence of simultaneous co-evolution toward this new paradigm by several key agricultural crops. It is proposed that those food-crop industries that most successful embrace this new paradigm will possess a competitive advantage in the marketplace; thus, affecting the "bottom line" of all those involved in the growing, processing, and selling of pecan nutmeats.

'Production Paradigm': From the early decades of the 20th Century until the late 1970's, progress accelerated as a consequence of dozens of major technological advances in pest control, fertilizers, cultivars, cultural strategies, water delivery systems, and labor saving machines. This technological revolution can be termed the 'Production Paradigm', and is a sub-component operating under the over-arching umbrella of the 'Green Revolution' era of world agriculture in which the philosophy of food production is based on developing technologies that increase both production and production efficiency of food, with primary emphasis on calories and a secondary emphasis on protein, but with relatively little attention to the total nutritional quality of food.

This Green Revolution, which continues to this day, has enabled world population growth to reach approximately 6.9412 billion people (www.ibiblio.org/lunarbin/worldpop) while essentially maintaining a global food surplus. Much of this increase came about due to production associated increases in wheat and rice, and to a certain extent maize. Although contributing a relatively minor role, pecan production increases also contributed in a small way to the success of the Green Revolution. This contribution is via an additive manner, being one of many specialty crops that collectively benefit world consumers.

'Sustainability Paradigm': Beginning in the late 20th Century, along with a philosophical shift inherit within the Green Revolution approach, the Production Paradigm began to transition toward a new system. This is the 'Sustainability Paradigm', which embraces preservation of resources and the environment, while simultaneously maintaining high productivity. Examples of technological advances within this new production philosophy is greater usage of cover crops, biocontrol agents, increased fertilizer and water use efficiency, recycling of prunings, tree transplanting, organic approaches, safer and more environmentally friendly pesticides, and improved pesticide use-efficiency.

'Food Systems Paradigm': Much of the following discussion is based on overarching conclusions of scientists studying the future of world agriculture (Welch, 1995; Welch and Graham, 1999, 2002, and 2005; Druxbury and Welch, 2002). It is increasingly understood by scientists and policy makers that the global food system is failing in that it does not provide most people with a balanced diet of nutrients. Infants, children, and women are the primary victims of this flawed system. It is estimated that well over 5 billion people, including most citizens of Western Civilization, suffer from some form of nutrient deficiency sufficient to adversely affect both length and quality of life. This state imposes substantial economic load on societies [reduced worker productivity, costs to treat chronic diseases (e.g., cancer, diabetes, strokes, and heart diseases)]; thus, the issue is of great importance to global society. Multiple societal forces appear now to be merging in a way that will likely trigger a transition to new and improved paradigm for U.S. and world agricultural production, unless "nipped in the bud" by major global geopolitical turmoil--such as war, economic collapse, or famine. It is the 'Food Systems Paradigm' proposed by Welch and Graham (1999; two world leaders in nutritional security). This paradigm is a merger of the concepts of productivity, sustainability, and human nutrition. Agriculture has yet to embrace the goal of sustainable nutrient output as a key dimension of its production systems. At the same time, the human health community has adopted a seriously flawed "supplementation" and "treat the symptom" approach to a Western Civilization and global "poor nutrition" and "poor health" issue arising from inadequate nutrition.

Human Nutrition: At the heart of the current world food problem is the issue of "Hidden Hunger". Hidden Hunger refers to a deficiency in the micronutrients (e.g., to include one of many different vitamins and minerals) required for good human health. Man's longevity and effectiveness is reduced when an essential micronutrient is absent or insufficient in his diet, regardless of how much food is otherwise eaten. Hidden Hunger confers great cost on world societies, reducing a nation's labor force productivity, lowering a nation's degree of education and technological abilities, adversely affecting efforts at national development, reducing mortality and morbidity rates, and greatly increasing national health care costs (Sanghvi,1996), There are about 51 nutrients thought essential for humans. These nutrients include water, carbohydrates, several amino acids (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine), two fatty acids (linoleic and linolenic acids), 11 macronutrients (Na, K, Ca, Mg, S. P, Cl; plus N, C, H, and O in the fatty acids and amino acids, water, and air), 13 micronutrient vitamins (A, D, E, K, C, B-1, B-2, B-3, B-6, folic acid, biotin, niacin, and B-12), and 17 mineral micronutrients (Fe, Zn, Cu, Mn, I , F, B, Se, Mo, Ni, Cr, Si, As, Li, Sn, V, and Co) (Welch, 2002). Pecan nutmeats are an excellent source of many of these essential nutrients, especially the mineral micronutrients. Pecan farmers are therefore important nutrient providers to Western Civilization, and are beginning to significant impact Eastern Civilization as a consequence of increased exportation of pecan nuts to China, India, and other Asian countries [where many people survive on energy rich, but nutritionally incomplete, crops brought about largely as a consequence of the 'Green Revolution' that led to great advances in yields of maze, wheat, and rice, but had the unintended consequence of increasing nutrient deficiencies in most of the world's population due to dietary reductions in traditional micronutrient-rich crops].

***Famine in Western Civilization*:** While famine in the developing world has the potential to rapidly escalate due to geopolitical issues and/or natural events, it is generally unknown or unappreciated that most citizens of Western Civilization suffer from famine. This Western Famine is subtle—*it is a famine of food quality*. Thus, nutrient malnutrition is not just a problem in the Third World, but is also a First World problem. For example, for the average U.S. citizens, >55% of meals are from non fresh sources –i.e., restaurants, or processed food from supermarkets. Such foods tend to be relatively low in certain key nutrients,

Table 1. Antinutrients

Antinutrients	Major dietary sources
Phytic acid or phytin	Legume and cereal grains
Certain fibers (cellulose, hemicellulose, lignin, cutin, suberin, etc.)	Whole grains (wheat, rice, maize, oats, barley , rye)
Certain tannins and polyphenolics	Tea, coffee, beans, sorghum
Hemaglutinins (e.g., lectins)	Legumes and wheat
Goitrogens	Brassicas and Alliums
Heavy metals (e.g., Cd, Hg, Pb, etc.)	Contaminated leafy vegetables and roots

yet high in sodium, sugars, and fats. It is noteworthy that the latter three components greatly influence our perception as to whether food is "good"; hence, increasing the likelihood of our purchasing more of the same. Processed food producers take clever advantage of our weakness for these three components to increase profitability and market share; thus, most processed foods are loaded with one or more of these. Additionally, just to hedge chances for repeat consumption, in the case of beverages, a bit of caffeine and other substances are an often added to improves chances of yet more consumption. Additionally, many foods and beverages contain "antinutrients" (i.e., factors that inhibit micronutrient uptake by the digestive system; examples are tannins and polyphenols). There are also many other factors contributing to the "food quality famine" of Western Man, one is the consumption of a relatively non diverse diet in terms of organic and mineral micronutrients.

Malnutrition is now recognized by the United Nations as being, by far, the number one cause of human death, with there being one death per second worldwide. It also causes impaired immune function, lower worker productivity, diminished intellectual performance, less educational attainment, a lower livelihood, higher birth rates and a lower standard of living (Welch and Graham, 1999). Many diseases that claim life are rooted in chronic nutrient deficiencies. Hidden Hunger is also a major contributing factor to

Table 2. Promoters of Fe, Zn and vitamin A bioavailability

Substance	Nutrient	Major dietary source
Certain organic acids (ascorbic acid, fumarate, malate, citrate)	Fe and/or Zn	Fresh fruits and vegetables
Hemoglobin	Fe	Animal meats
Certain amino acids	Fe and /or Zn	Animal meats
Fats and lipids	Vitamin A	Animal fats, vegetable fats
Selenium	I	Sea foods,
Fe, Zn	Vitamin A	Animal meats
B-carotene	Fe, Zn	Green and orange vegetables
Insulin and other non-digestive carbohydrates (probiotics)	Ca	Garlic, onion, wheat

the impact of influenza pandemics on the world population, as one or more micronutrient deficiencies can greatly increase susceptibility to infection.

The 'Big Five' Deficient Micronutrients: According to World Health Organization and Food and Agriculture Organization reports, roughly 1 billion people today still suffer from a "calorie (energy)-protein" deficiency. Recall that it was this form of deficiency that the Green Revolution addresses (i.e., a focus on relatively short-term food needs). A much greater food problem is that of Hidden Hunger, as it is estimated to affect approximately 3 billion people in a relatively obvious manner, and another 2 billion or so in a relatively subtle manner. The most limiting nutrients in both Western and Eastern diets are iron (Fe), iodine (I), vitamin-A, zinc (Zn), and selenium (Se). Deficiencies in these nutrients have a multitude of ramifications for both physical and mental health. For example, according to Welch (2002), Fe deficiency contributes to anemia, problem pregnancies, stunted growth, reduced resistance to infections, long-term impairment of mental function, decreased productivity and food energy conversion and impaired neural motor development; Vitamin-A deficiency leads to poor night vision, eye lesions, blindness, and reduced resistance to infections; Zn deficiency can cause growth retardation, delayed skeletal and sexual maturity and potency, dermatitis, diarrhea, and retarded immune function; iodine deficiency can cause mental retardation, brain damage, reproductive failure and goiters (this is why iodine is added to table salt in Western countries); and selenium deficiency greatly increases the risk of colorectal and prostate cancer in older males.

Bioavailability: The Food Systems Paradigm also takes into account the issue of micronutrient (organic and inorganic forms) 'Bioavailability'. Bioavailability can have great impact on malnutrition and Hidden Hunger. The bioavailability issue is complex, as a great number of factors influence the availability of nutrients within the human digestive system. Our digestive system requires about 1,000,000,000,000,000 cells (10^{15}) of microorganisms to meet the nutritional needs of 10,000,000,000,000 cells (10^{13}) in our body; thus, there are 100 times more microbial cells within our digestive system as there are total cells comprising our bodies. These microbes are a fundamental requirement for human life. Their symbiotic usefulness is greatly influenced by a host of factors that either inhibit or enhance the microbe-human interaction. These inhibitors and enhances are influenced by both genetic factors unique to the plant, as well as environmental factors affecting plant stress. These inhibitors are called "antinutrients". Antinutrients accumulate in plant products (e.g., leaves, seeds, fruit, and roots) when plants are stressed (i.e., for nutrient elements, water, light, etc.). Examples of antinutrients affecting the bioavailability of micronutrients within the human digestive system are phytic acid, fiber, tannins, polyphenolics, hemagglutinins, and heavy metals (cadmium, mercury, lead and silver). Conversely, a few examples of promoter substances include organic acids (e.g., ascorbic acid or vitamin-C, malate, citrate), ferritin, several amino acids, long-chain fatty acids, fats and lipids, beta-carotene, Se, Zn, and Vitamin-E.

***Conclusions*:** Our agricultural production practices have traditionally focused on maximizing yield while minimizing costs. In recent years, there has been in most Western Nations an increased focus on 'Sustainable Agriculture' in which preservation of the environment is also an important agricultural goal; thus, technologies that improve sustainability will continue to be developed and introduced into the pecan production system of the future. There has never been much attention given to development of farming strategies that focus on maximizing nutrient output. This is as true for pecan production as it is for agronomic crops. This aspect of pecan production is likely to become increasingly important as consumers become more demanding of high nutrient density foods, like pecan, as they become more aware of linkages between major diseases affecting health and longevity.

Pecan producers know that pecan nutmeats are exceedingly healthy, containing almost all of the essential nutrients required by humans. The industry has, almost unknowingly, in recent years begun to link itself to the issue of nutrition and Hidden Hunger; thus, taking initial steps toward embracing the Food Systems Paradigm. Examples include marketing nutmeats based on oil and antioxidant composition. While there is exist rudimentary knowledge regarding the composition of nutrients, antinutrients, and enhancers in pecan nutmeats, there remains need for much greater understanding. These knowledge gaps include not only nutmeat composition, but also how husbandry, processing, and marketing practices affect nutrient composition.

Table 3. Indispensable amino acids for humans

Amino acid
Histidine
Isoleucine
Leucine
Lysine
Methionine
Phenylalanine
Threonine
Tryptophan
Valine

As with crops in general, the type, timing, amount, and method of application of fertilizers, applied to orchards, can greatly influence organic and inorganic micronutrient density (concentration) of pecan nutmeats. For example, excessive nitrogen can lead to substantial reductions in nutrient density of nutmeats; whereas, increasing potassium nutrition of trees can greatly increase nutmeat nutrient density. The optimization of tree potassium (K) nutrition is likely to have greater positive effect on maximizing overall nutrient density of nutmeats than any other element; yet, we still know little about how to substantially and economically increase tree K nutrition over the long-term. Additionally, the complex antagonistic and synergistic interactions among the many macro- and micronutrients is another realm in which greater knowledge about how orchard cultural strategies influence nutrients, enhances, and antinutrients.

There is also a near dearth of information regarding genetic variability in composition of nutmeats and how the environmental interacts to affect this composition. There undoubtedly exists great potential for increasing the organic and inorganic micronutrient composition, as well as antinutrient and enhancer composition, of pecan nutmeats via breeding. There is also potential benefit from the introduction of exotic genes (Genetic Modified Organism—GMOs) from other crops as they are prove efficacious for increasing specific micronutrients or enhancers, or for reducing specific antinutrients. This is a realm that has been largely ignored, even though USDA-ARS programs in Georgia and Texas, and the University of Georgia, possess an invaluable wealth of wild and semi-domesticated genetic resources that undoubtedly possess genes that can be stacked to confer much greater nutritional quality to nutmeats. Additional high value gene resources are undoubtedly lurking with the genome of pecan's several hickory cousins, which can theoretically be transferred to produce far superior pecan cultivars.

In order for the U.S. pecan industry to be on the cutting edge of an emerging *Food Systems Paradigm*, it must somehow find a way to increase research resources. This is unlikely to be accomplish without first cultivating an alliance with urban consumers. This will necessarily involve better educating consumers regarding the issues of Hidden Hunger; how it affects them and their families, and why they need to ally with farmers to improve micronutrient composition and density of foods they, and their posterity, consume. The advances discussed herein will increasingly be adapted by producers

Table 4. Fatty acid composition of pecan kernels. Increasing nitrogen fertilization reduces total fatty acid concentration of kernels, with oleic acid being reduce, but with linoleic acid increased.

Fatty acid type	Concentration (%)
16:0	4.6 - 7.0
18:0	1.5 – 3.8
18:1ω9 (oleic acid)	48.2 – 73.9
18:2ω6 (linoleic acid)	16.0 – 40.6
18:3ω3	0.70 – 3.4
Others	0.50 – 1.0

of other tree-nut crops competing with pecan in the marketplace; hence, the U.S. pecan industry needs to be aware of these issues and potential changes in consumer demand, and consider how best to adjust to this new paradigm. Additionally, improving ties between producers, shellers, and processors so as to focus limited resources on sponsoring clinical research linking pecan's rich composition of essential human nutrients to health issues (e.g., heart disease, diabeties, hypertension, neurological disorders, etc.) will greatly benefit pecan's competitive position for the food dollar.

Table 5. Vitamins in pecan kernels

Vitamin	Amount (mg/100 g kernel)
Vitamin-C	1.10
Thiamin	0.66
Riboflavin	0.13
Niacin	1.17
Pantothenic acid	0.86
Foliate	0.022

Table 6. Elemental composition of pecan kernels

Element	Amount (mg/100g kernels)	Element	Amount (mg/100g kernels)
Fe	2.20	Sr	0.58
Co	Trace	Ba	0.56
Cr	0.12	Na	0.44
Al	Trace	P	450
Mn	3.28	K	460
B	0.62	Ca	5.8
Zn	7.02	Mg	140

Table 7. Percentage of recommended dietary allowances (RDA) for adults*

Mineral	Males (% RDA)	Females (% RDA)
Ca	3	3
Cu	56	56
Fe	14	6
Mg	13	16
Mn	83	106
P	17	17
K	4	4
Na	0	0
Zn	17	**24**

*Based on 42.5 g (or 1.5 ounce) pecan serving (i.e., 1 serving of kernels)

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