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Trade-Offs in Agriculture and Nutrition

Presumably since the dawn of agriculture, humans have measured their farming success mainly by the size of their crops. Many environmental and genetic methods can increase crop yields, including irrigation, fertilization, weed and pest control, choice of cultivated variety, and selective breeding. These methods applied to grains culminated in the "Green Revolution" of the 1960s and '70s, greatly increasing yields of wheat, rice, and maize.

Unfortunately, in recent decades we have learned that increased yields may reduce concentrations of some nutrients. We should not assume that plant composition remains constant as we increase yield. A 1981 review in *Advances in Agronomy* discussed the widely cited "dilution effect," in which yield-enhancing methods like fertilization and irrigation may decrease nutrient concentrations (an environmental dilution effect). Recently, evidence has emerged that genetically based increases in yield may have the same result (a genetic dilution effect). Either way, modern crops that grow larger and faster are not necessarily able to acquire nutrients at the same, faster rate, whether by synthesis or by acquisition from the soil.

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Thus, there can be trade-offs between yield and nutrient concentration. Other kinds of genetic trade-off are well known. When breeders select for one resource-using trait, such as yield, less resources remain for other resource-using functions. For example, there may be trade-offs between the number of seeds and their size or between yield or growth rate and pest resistance. In tomatoes, there are reported trade-offs between yield (harvest weight) and dry weight, between yield or fruit size and vitamin C, and between lycopene (the primary color of tomatoes) and beta-carotene (vitamin A precursor).

How large and widespread are nutrient trade-offs? A recent report with my coauthors Melvin Epp and Hugh Riordan, "Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999" (J. Am. Coll. Nutr. 23: 669-682, 2004), suggests answers for one group of foods. Building on research from the United Kingdom, we studied 50-year changes in U.S. Dept. of Agriculture food composition data for 13 nutrients in 43 garden crops—vegetables plus strawberries and three melons. We found apparent declines in median concentrations of six nutrients: protein –6%, calcium –16%, phosphorus –9%, iron –15%, riboflavin –38%, and vitamin C about –20%. There were no statistically reliable median changes for ash, vitamin A, thiamin, niacin, energy, carbohydrate, or fat.

Among individual foods, there was much variability. Changes within the central half (interquartile range) of our foods varied, for example, from –15% to +6% for protein and from –53% to +4% for riboflavin. A subset of individual foods and nutrients with the best data suggests that about one-fourth of them have reliable increases.

We postulate that the median declines in nutrient concentration reflect primarily unintended side effects of increased yields (environmental and genetic dilution effects), whereas the increases in some individual foods and nutrients reflect primarily genetic variability associated with changes in cultivated varieties. Many studies show marked genetic variability in nutrient concentrations.

Possibly, 50-year changes in analytical methods account for some of the apparent changes, and other potential confounding factors exist. But there is recent, direct evidence of genetic trade-offs between yield and mineral concentration in broccoli (calcium and magnesium), and in wheat (iron, zinc, copper, selenium, phosphorus, and sulfur). Low- and high-yield varieties were grown and analyzed side-by-side, eliminating key uncertainties that apply to historical data. Correlation coefficients between yield and nutrient concentrations were entirely negative for 14 hard red winter wheats, and most coefficients were substantial, ranging from –0.11 to –0.87 and averaging –0.52. For 27 commercial broccoli hybrids, correlation coefficients between yield and calcium and magnesium ranged from –0.46 to –0.69. There seems little doubt that sizable genetic trade-offs exit, but we do not yet know their breadth.

We doubt that inadequate soil minerals can explain most of our findings. Nitrogen, phosphorus, and potassium are routinely added to soils if needed. Yet we find median declines for all three associated nutrients—protein, phosphorus, and ash (–6%, not quite statistically significant).

Our findings give one more reason to eat more vegetables and fruits, because for nearly all nutrients they remain our most nutrient-dense foods. Our findings also give one more reason to eat fewer refined foods (added sugars, added fats and oils, and white flour and rice), because their refining causes much deeper and broader nutrient losses than the declines we find for garden crops.

Technology should allow us to increase selected nutrient concentrations. But will we learn 20 or 40 years later that there were new, unintended side effects? Another question looms large: Is it wise, in the era of technology, to keep crop size (or even the concentrations of a few, selected nutrients) as our primary measure of farming success? ●

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