KEYNOTE SPEECH ON THE RISING LEVELS OF ATMOSPHERIC CARBON DIOXIDE (CO_2) INTENSIFY MALNUTRITION

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Malnutrition is a top global challenge. As far as hunger is concerned, we have about 800 million people that do not have enough food. But when it comes to malnutrition, just to mineral undernutrition, we have over 1 billion people at risk of zinc deficiency, over 1 billion people at risk of iron deficiency; and the latest estimates say that about 3.5 billion people, almost every other person on Earth, is at risk of dietary calcium deficiency. Malnutrition not only means undernutrition but also over nutrition – overconsumption of calories. Over 2 billion people are estimated to be overweight and over 600 million are obese. What is particularly worrisome is that both over nutrition and undernutrition can co-exist in the same family or even in the same individual.

Malnutrition particularly heavily affects Asia and the Pacific region. When we look at the rates of people being overweight, the fastest rise is seen in Southeast Asia and the Pacific. Nearly half of the world's population that is experiencing the double burden of stunting among children under 5and overweight adult females is living in Southeast Asia and the Pacific. The prevalence of the double burden (% stunting, % overweight) is as follows: Philippines (32, 29); Indonesia (36, 26); and Papua New Guinea (43, 50). Overconsumption has been linked to junk food: "high availability and promotion of processed, low-cost (cheap), energy-dense foodstuffs." Haddad et al (2015).

Nutrition is an extremely complicated subject but here I take a very simple and unusual perspective on junk food, which originated in the Western world and is culturally alien to many countries. It is heavily promoted by the Big Food industry because it is highly profitable. It is so profitable because it is created by injections of fats and sugars, which are among the cheapest calories available, and also it tastes good. There is a lot of debate about fats vs sugars but from an elemental perspective, both fats and sugars are made out of three elements: carbon (C), hydrogen (H), and oxygen (O). So by injecting fats and sugars, the big food industry dilutes essential minerals and micronutrients with these three elements: C, H, and O. Junk food is a processed food; what about unprocessed food, vegetables and fruits and staple crops? Can we be assured that the quality of these foods is not declining? I will be making the case today that with every passing year, the quality of all crops is declining as well. In other words, nutrient density in these crops is declining too.

Let's take a simple – elemental or stoichiometric – perspective on photosynthesis under rising CO_2 levels. Plants take CO_2 from the air and water from the soil, which they split into hydrogen and oxygen to make sugars and starches. CO_2 concentrations have been steadily increasing over the last few decades are projected to double within this century, possibly within our lifetimes. When there is more CO_2 in the air, most plants make more sugars and starches. Some of those can be stored within plant cells, in special compartments: vacuoles and plastids. These extra sugars and starches do not really hurt plants; but let us conjecture what will happen to plant eaters, including humans. Just as in the junk food example, those extra C, H, and O would end up diluting essential minerals with every bite of plant-based foods.

Seventeen years ago, I made the argument that rising levels of CO_2 will affect human nutrition by decreasing nutrient density of crops and wild plants globally. At that time there were only two-dozen studies that reported mineral densities in plants grown at elevated CO_2 conditions. As shown on the figure, zinc, iron, magnesium, calcium are declining in wheat and the mineral density in leaves is declining as well. Back in 2002, millions of people were already deficient in iron, zinc, or iodine; so it was logical to conclude that high levels of CO_2 should intensify the problem of micronutrient malnutrition.

While this argument is logical, it involves several disciplines: plant physiology, agriculture, human nutrition, human health etc. Specialists within these disciplines looked at it and did not buy into the whole argument. So there was a lot of skepticism towards the concept. To prove that rising CO_2 decreases nutrient densities we would need to measure plant samples from CO_2 experiments. For example, in rice, CO_2 was maintained at a high level within a ring in the field and rice grown within this ring could be compared with rice grown at identical conditions but at ambient CO_2 levels in the same field. Plant physiologists do these experiments for various reasons: to measure yield and plant parameters; occasionally they do measure mineral content. These experiments could also be run in open-top chambers, greenhouses etc.

I compiled data that researchers published worldwide; relatively more data has been published on protein levels in crops grown in elevated CO_2 conditions. In 2008, Daniel Taub and collaborators analyzed the available data and showed that protein level significantly declined in the grains of staple crops and potato. It took 12 years to compile enough data to show that rising CO_2 levels decreased mineral density in crops and wild plants.

So thanks to all those researchers running experiments in Asia, Europe, the United States and Australia, I was able to compile data on 25 minerals in 130 plant varieties. To this day it remains the largest study on the issue. These are the results for plants grown at elevated CO2 conditions: the carbon content appears to increase in plant tissues but nearly all the essential minerals including zinc, iron, magnesium, calcium, potassium decline, including protein, which is represented by nitrogen (N). Ionome is collectively all the minerals and trace elements in an organism and rising CO_2 levels appear to downshift the plant ionome by 8%. What is important to bear in mind that this is not an isolated effect only occurring in one region of the world or in one specific plant species; this is a systemic and pervasive global effect.

This decline in the ionome or nutrient density is found in major staple crops such as rice, wheat, barley, and potato. This effect of rising CO_2 levels on nutrient density of plants is found in temperate areas, in subtropics and every country for which we have sufficient data. Elevated CO_2 levels also decrease nutrient density in wild plants, trees, herbaceous plants etc. It is a systemic and pervasive effect on nearly all plants globally. As CO_2 concentrations rise and plants accumulate more sugars and starches, these dilute not only minerals but other nutrients.

Last year, we published a study analyzing grains of 18 rice cultivars grown at elevated and ambient CO_2 conditions in China and Japan. As expected, we found that zinc, iron and protein decline in most of these rice cultivars. But interestingly, we also found that B-vitamins, such as B1, B2, B5, and B9, declined in essentially all rice cultivars for which wedata are available. In 2019, we published a study about effects of elevated CO_2 on carotenoids plants. In both plant and human tissues, carotenoids protect against oxidative stress; recent trials showed that when diet is supplemented with certain xanthophylls, which are a class of carotenoids, not only several parameters of vision improve but also memory improves in human subjects.

What is worrisome is that when we analyze the data from elevated CO_2 experiments reporting carotenoid levels, we find a significant decline in carotenoid density. It appears that this happens not only because of dilution by extra starches and sugars but also because the genes responsible for carotenoid biosynthesis become downregulated. In other words, plants appear to have less need for carotenoids at elevated CO_2 conditions. That does not hurt plants but it can hurt nutrition of plant consumers, including humans.

Some final thoughts: We have several methods of improving crop quality, from biofortification via conventional breeding, to engineering and to various ways of enriching soil with minerals. We know they will improve nutrient density of crops. However, the problem lies with incentives in agriculture, which are essentially based on yield. The Green Revolution, synthetic fertilizers etc. are all about increasing food quantity while food quality is disregarded. Now we know that rising levels of CO_2 work against us. The nutrient density of most crops and wild plants globally will keep declining with every passing year as CO_2 concentrations keep on rising. I feel that we need to fundamentally change incentives so that farmers are paid for improved crop quality; then they will have financial incentives to use the available tools to boost nutrient intensity in crops. This will help us mitigate the negative effect of rising CO_2 on plant quality and human nutrition.