For the past 50 years, the country has introduced high-yielding rice and wheat varieties at breakneck speed to achieve food security. A study led by scientists with the Indian Council of Agricultural Research (ICAR) has for the first time looked at the food value of these modern-bred grains, and delivers some dire warnings: the food grains that we eat have lost food value; instead they are accumulating toxins. Worse, by 2040, the grains will become so "impoverished" that they would worsen the country’s growing burden of non-communicable diseases.

A report by SHAGUN
YOU ARE what you eat, or, rather, what you grow to eat. Imagine an entire population eating something that has little food value—something that is devoid of nutrients such as a host of vitamins which are essential for growth, disease prevention and maintaining overall health and well-being.

“This is the future we are hurtling towards,” says Sovan Debnath, a soil scientist at the Indian Council of Agricultural Research (ICAR) under the Union Ministry of Agriculture and Farmers Welfare.

In November 2023, Debnath and 11 other scientists from ICAR, Bidhan Chandra Krishi Viswavidyalaya—another premier agricultural research institute in West Bengal—and the National Institute of Nutrition in Telangana published a seminal study that says the Green Revolution has helped India achieve food security, but by compromising its nutritional security. In a first, the study reports that breeding programmes focused on developing high-yielding varieties have altered the nutrient profiles of rice and wheat, two major staple food grains of India, to the extent that their dietary significance to the population has diminished. While chasing yield, the plant genetics have been tinkered with so much that they no longer do the fundamental job of delivering nutrition from the soil to the grains.

Between 2018 and 2020, the scientists grew “landmark” high-yielding cultivars of rice and wheat released in succeeding decades since the Green Revolution was introduced in 1967. Cultivars are plants developed to have particular features. As many as 16 cultivars were chosen for rice and 18 for wheat. “Around 1,500 different cultivars of rice and wheat have been released since the 1960s. The landmark ones were selected after discussions with breeders of different institutes in the country. These had been popular and thus were adopted widely across the country in a particular decade. We stopped at the 2000s for rice and at the 2010s for wheat as after those decades we did not find cultivars that could be called landmark,” says Debnath. Seeds for the cultivars were procured from gene banks.

Evaluation of the nutrient profiles of the harvested grains showed that rice and wheat, which meet over 50 per cent of the
daily energy requirements of people in India, have lost up to 45 per cent of their food value in the past 50 years or so. At this rate, the grains will become impoverished for human consumption by 2040, they estimate.

What’s more worrying is that along with diminishing nutrient levels, the concentration of toxic elements have increased in the grains. For instance, in the past 50 years, the concentration of essential nutrients like zinc and iron has decreased by 33 per cent and 27 per cent in rice, and by 30 per cent and 19 per cent in wheat, respectively. In contrast, the concentration of arsenic, a toxic element, in rice has increased by 1,493 per cent. In other words, our staple food grains are not only less nutritious, but also harmful to health.

The scientists have also assessed the health impact of this “historical shift” in the nutrient profiles of rice and wheat, and warn that the impoverished staple grains could worsen the country’s growing burden of non-communicable diseases (ncds).

It is well known that essential and beneficial nutrients such as phosphorus (P), calcium (Ca), silicon (Si) and vanadium (V) play an important role in bone formation; zinc (Zn) is crucial for immunity, reproductive and neurological development; and iron (Fe) is key for haemoglobin formation. The depleted concentration of these essential nutrients in the staple grains could result in higher prevalence of diseases related to the neurological, reproductive and musculoskeletal systems, the scientists write in *Scientific Reports*, published as part of multi-disciplinary science journal *Nature*. There is also strong evidence that oral ingestion of metal toxicants, such as arsenic, chromium, barium and strontium has toxic effects like lung cancers or chronic respiratory diseases, cardiovascular diseases, hyperkeratosis, renal toxicity and impaired bone calcification. They further note that over the years, the consumption of nutrient-rich cereals (sorghum and other millets) has reduced. Together, these put the Indian population at a higher risk of nutritional insecurity.

The study’s findings corroborate a report by the Indian Council of Medical Research (icmr) that indicates a 25 per cent rise in NCDs among the Indian population from 1990 to 2016. Estimates show that India is home to one-third of the 2 billion global population suffering from micronutrient deficiency. Though the National Family Health Survey reports show a decline in child stunting—an indicator of micronutrient deficiency—between 2015-16 and 2019-21, the rate is still significantly high at 35 per cent among children under five years of age. In 161 districts, more than 40 per cent children under five years of age suffer from stunting. While there could be several reasons for such high prevalence of micronutrient deficiency in India, the scientists assert that the diminishing food value in the staple food grains could be a significant contributor to the problem.

**SYSTEMATIC ELIMINATION**

Agricultural practices that the Green Revolution shaped have often been criticised for their impact on the environment and food systems. But discussions have rarely moved beyond the impact on soil degradation, surface water pollution, groundwater depletion and monocropping. The *Scientific Reports* study has for the first time put the spotlight on the impact of Green Revolution on the nutritional security of India.

Debnath says the 2023 study is an extension of another study he and a few other scientists from ICAR and Bidhan Chandra Krishi Viswavidyalaya conducted in 2021, to explore the reasons for zinc- and iron deficiency in populations dependent on a cereal diet. They conducted experiments with high-yielding cultivars of rice and wheat released in succeeding decades since the Green Revolution and observed a downward trend in grain density of zinc and iron in those cereals. There can be two reasons for this depletion: poor availability of nutrients in the soil and inefficient cultivars that fail to deliver the nutrients to grains. While enough studies have been reported across the globe to show a
Decline in essential minerals

High-yielding rice and wheat varieties released over last 50 years show drastic decline in concentration of key essential micronutrients in food grains. The decline is more severe in rice than wheat.

Note: The left vertical axis represents mineral concentration in wheat and the right vertical axis represents mineral concentration in rice. All units are in mg per kg. Asterisks indicate significant differences between the observed means of the decades for the cultivars of rice and wheat released up to the 2000s and the 2010s, respectively (*P < 0.05; **P < 0.01; ***P < 0.001; ****P < 0.0001).

Source: “Historical shifting in grain mineral density of landmark rice and wheat cultivars released over the past 50 years in India”, Scientific Reports, November 2023.

significant depletion in grain densities of zinc and iron in the modern, high-yielding cereal cultivars, not much evidence is available to establish that poor soil mineral availability leads to poor mineral concentration in food grains, they write in the study published in *Environmental and Experimental Botany*. Rather, the experiment showed that the decrease in grain mineral densities coincided with the introduction of semi-dwarf, high-yielding cultivars. “These findings led us to infer that the modern-bred cultivars of rice and wheat are less efficient in sequestering Zn and Fe, despite their abundance in soils,” the team states.

The 2021 study hinted at a disruption in the crop plants’ inherent intricate regulatory mechanisms for balanced uptake and distribution of mineral nutrients, inadvertently created in the course of the past breeding programmes. The team’s latest study was to unearth the existence and extent of the problem.

To rule out any relation between grain mineral density and the deficiency of nutrients in soil, the crops were grown on the experimental soil that contained...
Alarming rise in toxic elements

High-yielding rice and wheat varieties released over last 50 years show higher accumulation of toxic elements in food grains. Toxin accumulation is particularly severe in rice.

Note: The left vertical axis represents mineral concentration in wheat and the right vertical axis represents mineral concentration in rice. All units are in mg per kg. Asterisks indicate significant differences between the observed means of the decades for the cultivars of rice and wheat released up to 2000s and 2010s, respectively, respectively (**P < 0.05; ***P < 0.001; ****P < 0.0001)

Source: “Historical shifting in grain mineral density of landmark rice and wheat cultivars released over the past 50 years in India”, Scientific Reports, November 2023
This simply means that plants have lost their capacity to take up nutrients from the soil. Biswapati Mandal, soil scientist at the Bidhan Chandra Krishi Viswavidyalay and co-author of the study, explains: “As the country started breeding for high-yield characteristics, it led to genetic exclusion of traits related to enhancing grain mineral loading. The high yields, took away focus from food value, particularly total mineral elements content, known as ionome.”

DILEMMA AMID HUNGER
When the Green Revolution began in India, the aim was to feed the rapidly growing population—which had jumped by 21 per cent in just 10 years to reach 439 million in 1961—and to become self-sufficient in food production. The country by then had suffered frequent famines and food shortages; hunger was widespread. So main motive of agricultural scientists was to improve yield. “We were never in a position to think about malnutrition,” says Debnath, adding that the country released its first official reports on malnutrition only after the 1980s.

The traditional rice and wheat varieties or landraces grown in the country before the Green Revolution had several crucial traits. Developed over time largely through selection by farmers, these landraces were not only highly suited for the local agroecology, but also had rich nutritional content. During the Green Revolution, these landraces were utilised in breeding programmes and crossed to make the new varieties. Dwarf genes isolated from high-yielding varieties were inserted to ensure a higher distribution of photosynthates (products of photosynthesis that are usually simple sugar) into the grains, thereby increasing the grain size and improving yield. “While photosynthates reached the grain in sufficient quantity, it was not necessary that nutrient and minerals also reached in the same and equal proportion. So slowly, the trait of taking more nutrient by the grain got lost,” says Rubina Khanam, a scientist with National Rice Research Institute (nrri), Cuttack, Odisha, and co-author of the study. With the cross-breeding of landraces picking up pace, the original parent varieties started getting excluded from the breeding process. The native, useful genes also started to slowly decrease as the country focused on more high-yielding varieties.

“After the 1980s, the focus of breeders shifted to developing varieties that are resistant to pests, diseases and tolerant to several stresses like salinity, moisture and drought,” says Mandal. “They did not have the luxury of thinking whether the plants were taking nutrients or not,” he adds.

“We gained quantity but lost quality,” says Khanam, who works with different rice varieties. She highlights another fallout of Green Revolution. Amid continuous genetic tampering under the modern breeding programme, the plants have also lost their natural evolutionary defence mechanisms against toxicants. “In a plant, both the good and bad mineral elements are absorbed...
through the same channel. So it is normal for the toxic elements to reach till the stalk. But rice is an intelligent plant. So it uses its genetic potentiality to screen out the elements that are either not good for itself or for humans and does not allow the elements to reach the grain. For example, arsenic is not very harmful to the plant but very harmful to humans. So, whenever high amount of arsenic is present in the soil, the rice plant would automatically switch off the transporter’s ability to take up that element. Or it would deploy another mechanism to deposit the toxic metal in some unused part of the plant, like in the vacuole. This inherent mechanism of the plant has now deteriorated,” Khanam says.

Now, to increase grain yield, plants are taking particular nutrients in high amounts. Through the same channel, the negative elements also reach the stalk in high amounts. The great quality of screening present in good rice varieties is now lost, she adds.

This is also the reason that the accumulation of toxic elements was higher in rice than in wheat. For instance, concentration significantly decreased from 0.032 mg per kg in wheat cultivars released in the 1960s to 0.015 mg per kg (53 per cent-drop) in cultivars of the 2010s. There was also a downward trend in the concentration of lead and chromium for wheat.

Scientists point towards the difference in the growing conditions of the two crops as one of the possible reasons for more increase of toxins in rice compared to wheat. Rice is grown in submerged conditions. When soil is flooded, an anaerobic condition is developed, which means that air does not reach the soil. Under this condition, heavy metals undergo chemical transformation and take a form which is more soluble, thus coming in more “plant available” form. And the roots cannot be distinguished.

WORLD WIDE DESPERATION

The pattern is not unique to India. Scientists from several other countries have also reported similar depletion in nutrition levels in food grains since the introduction of high-yielding varieties.

One such study was led by Ming-Sheng Fan from the Rothamsted Research, UK, which evaluated mineral concentration of archived wheat grain and soil samples from the Broadbalk Wheat Experiment, one of the oldest continuous agronomic experiments in the world that started in 1843. The researchers chose samples from eight plots; and in all them, the study found significant decreasing trends in the concentrations of zinc, copper, iron and magnesium in wheat grain since the 1960s. “The concentrations of zinc, iron, copper and magnesium remained stable between 1845 and the mid 1960s, but since then have decreased significantly—20-30 per cent—which coincided with the introduction of semi-dwarf, high-yielding cultivars. In comparison, the concentrations in soil have either increased or remained stable,” the scientists wrote in the Journal of Trace
Depletion in mineral diet quality
Nutritional quality of rice and wheat cultivars continue to deteriorate with each passing decade

Elements in Medicine and Biology in 2008. The Green Revolution has unintentionally contributed to decreased mineral density in wheat grain, the study found.

The 2021 study led by Debnath also showed that the large increase in the proportion of the global population suffering from zinc and iron deficiency over the last four decades coincided with the global expansion of high-yielding, input-responsive cereal cultivars released in the post-Green Revolution era.

In 2006, scientists from the US showed that zinc and iron concentrations in food grains decreased significantly with the release of 14 wheat cultivars from production eras spanning more than a century. The study was published in the Journal of the Science of Food and Agriculture in 2006.

In 2015, researchers in Iran found that during the 70 years of introduction of high-yielding varieties, yield has shown a small improvement, while the concentrations of protein, iron and zinc have shown a drastic decline. “These showed breeders’ attention was often paid to enhancing grain production and they mostly neglected the quality of wheat production specially protein, iron and zinc,” said their study published in European Journal of Agroeconomy. “These relationships might be attributed to a dilution effect of the minerals due to the increased grain yield of most recent genotypes which is impacted by both environmental and genetic factors,” it said.

UNDOING BLUNDERS
Irrespective of the reason, a significant effort is being made in India to improve the nutritional profile of food grains. This time, agricultural scientists have turned to landraces and wild species of cultivated varieties for answers. In the past 10 years, scientists at ICAR and agriculture universities have undertaken germplasm exploration across the country to find donor varieties that are high in nutritional content under a special project on biofortification, launched by the Union government.

“We are trying to identify donors that are
rich in at least one nutrient, for instance zinc or iron,” says Sanghamitra Samantaray, who heads the crop improvement division at ICAR’s National Rice Research Institute, Cuttack, Odisha. “Since strong donor varieties are not easy to find, we are also creating nutrient profiles of landraces conserved by farmers and of wild varieties that are not cultivated but are naturally growing,” she says.

G Padmavathi, principal scientist, Indian Institute of Rice Research (IIRR), Hyderabad, explains the institute’s plan of using the donor varieties in biofortification. Most donor varieties are usually poor yielders, photosensitive, suffer from lodging, and have other negative traits. They need to be crossed with either already released high yielding varieties or unreleased promising lines, so that there is no compromise no yield, Padmavathi says.

Since 2016, three national plant breeding institutes under ICAR—the National Rice Research Institute (NRRI), Cuttack; the Indian Institute of Rice Research (IIRR), Hyderabad; and the Indira Gandhi Krishi Vishwavidyalaya, Raipur under the All India Coordinated Research Project on Rice—have released 10 such zinc- and protein-rich rice varieties. Other institutes under ICAR have developed 43 wheat varieties that are rich in protein, iron and zinc. “There are many malnourished children in India who do not get enough protein-rich food. But they are habituated in taking rice and wheat. So, these varieties can provide them that required nutrition,” says Samantaray.

So far, institutes under ICAR have developed 142 biofortified varieties. The list includes 124 field crops (10 rice varieties, 43 wheat, 20 maize, 11 pearl millet, 13 small millets, one linseed, two lentil, two chickpea, one mungbean, one field pea, one urd bean, eight mustard, seven soybean, one sesame, three groundnut varieties) and 18 horticultural crops (five sweet potato varieties, three amaranthus, two greater yam, two potato and one each of cauliflower, okra, grapes, banana, guava and pomegranate varieties).

“Under biofortification, donor varieties are crossed with already released high-yielding varieties or unreleased promising lines so that yield is not compromised”

G Padmavathi, principal scientist, Indian Institute of Rice Research, Hyderabad

“There should be an integrated process where breeders can use multiple parents to pool genes and traits into one variety of different packages”

Abhinandan Patil, scientist, Agharkar Research Institute, Pune

However, these varieties are far from being popularised and adopted by farmers on a large scale. “This is because the task of convincing farmers to switch to a new cultivar is huge. Then, there are problems like availability of seeds,” says Debnath.

During the past six years, about 10 million hectares (ha), or 6 per cent of the country’s total area under farming, has been brought under biofortified varieties, including that of wheat, rice, pearl millet, mustard and lentil, as per a reply by the Union government in Lok Sabha on December 8, 2023. The statement does not give any bifurcation of area under rice and wheat, but according to an ICAR document on biofortified varieties published in 2022, only 25,565 kg and 1,043,014 kg of breeder seeds of rice and wheat, respectively, have been produced. To put this in context, in the kharif season of 2023, rice was sown on 41 million ha. The optimum seed rate is 40 kg per ha on average, with the transplanting method commonly used in the country. The
Food not for health

Adverse health effects of mineral diet quality has steadily increased in high-yielding rice varieties, exceeding constructive effects in 2022. For wheat, adverse and constructive effects continue to deteriorate.

25,565 kg seed produced would cover just about 639 ha. Similarly, in the ongoing rabi season, about 30.73 million ha of wheat has been sown till December 15, 2023. And given that the seed rate of wheat is around 100 kg per ha, the 1,043,014 kg biofortified seeds will be sown in about just 10,430 ha.

Besides, the efforts on fortification as of now is focused on zinc, iron and protein. Scientists Down To Earth spoke to say other biofortification of other essential elements like manganese, copper and calcium will take some time as breeding and releasing any variety is a long and arduous task, and can take about eight years on average.

To fast-track the process, a few scientists are also experimenting with agronomic biofortification, which involves using micronutrients as fertiliser or spraying it directly on the leaves. However, the process is expensive. Environmental factors like rainfall soon after the spray can also nullify the effect, cautions Debnath.

Abhinandan Patil, scientist with Agharkar Research Institute in Pune and a plant breeder, says research institutions developing varieties need to overhaul their breeding process. “There should be an integrated mainstreaming process where breeders can use multiple parents to bring out new varieties by pooling genes and traits into one variety of different packages. There is no need for so many different varieties. Those just confuse the farmers and consumers,” Patil adds.

While yield continues to preoccupy the agenda of farmers as well as breeders in the face of food shortage because of extreme weather events and global conflicts like the Russian invasion of Ukraine, the government and its various research and extension institutes have their task cut out. If India has to have any chance in arresting malnutrition, micronutrient deficiency burden and other NCDs, nutrition has to be made a priority at par with yield if not more, and popularising these varieties among farmers has to be done on a mission mode. @down2earthindia

Note: The constructive and adverse effect on the Y axis represents the average diet quality indexing scores of elements having beneficial and harmful effects on human health, respectively. This mineral diet quality index was computed based on the concentrations of essential beneficial and toxic mineral elements in the grains of rice and wheat cultivars.

P <0.0001

Source: “Historical shifting in grain mineral density of landmark rice and wheat cultivars released over the past 50 years in India”, Scientific Reports, November 2023