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Climate-smart wheat for nutritional security: Bridging research, extension and farmer adaptation

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Wheat accounts for one-fifth of the total food calories and protein consumed by the global population. It is the second most important foodgrain crop after rice in India and is the backbone of India's food basket. For millions of rural families, wheat is not just a crop, it is daily bread, livestock feed, a source of income, and nutritional security rolled into one. But a quiet crisis is unfolding in wheat fields across the country due to climate change. Climate change poses significant challenges to global wheat production, necessitating adaptation strategies to ensure food security. Even if farmers work hard to maintain yields, climate change is silently reducing the nutritional quality of wheat. This emerging problem, often called the hidden hunger crisis, has serious implications for household diets, rural health, and food security. Increased awareness of the environmental changes and health benefits of plant-based diets have directed current research of wheat in human nutrition to sustaining abundant wheat production while enhancing its technological and nutritional quality. Addressing these challenges requires multidisciplinary approaches, integrating advanced technologies, and investments in research and innovation.

Keywords: Awareness, Climate change, Hidden hunger, Multidisciplinary approach

THOUGH wheat looks same, yet the nutrition is changing. Research from India and around the world shows that rising temperatures, more frequent heatwaves, and elevated carbon dioxide levels affect the way wheat plants accumulate nutrients. Wheat exposed to high CO_2 often produces bigger grains but these grains tend to have lower protein, zinc, and iron content. This is known as the nutrient dilution effect. Under elevated CO_2, plants grow faster and accumulate more carbohydrates. But their ability to absorb or transport nutrients from soil does not increase at the same rate. The result is more starch and fewer essential micronutrients. This means a *chapati* that looks normal on the plate may actually contain fewer nutrients than it did a decade ago.

Heat stress: A bigger threat

Heatwaves during the grain-filling stage are becoming common in the Indo-Gangetic plains. Even a few days of high temperatures can change the structure of wheat proteins and reduce grain quality significantly. Some of the visible effects include poor *chapati*-making quality, reduced gluten strength, lower test weight, loss of grain hardness and faster shriveling in late-sown wheat. Recent research has highlighted risks of simultaneous crop failures due to heat and/or drought in 'breadbaskets' across the globe and extremes in temperatures and precipitation (including



Wheat field

drought) are already attributed with 40% of interannual production variability in wheat. For farmers who already face tight margins, a drop in grain quality can mean lower market price and poorer nutritional value for consumers. The impact of climate stress is more pronounced on small and marginal farmers because large farmers can compensate the heat stress through irrigation, timely sowing, and better inputs. But small and marginal farmers, especially in eastern Uttar Pradesh, Bihar, Madhya Pradesh, and parts of Rajasthan, face multiple constraints like delayed sowing after paddy harvesting, limited access to irrigation, more exposure to heat and water stress, poor access to quality seed, reduced capacity to adopt climate-resilient technologies, etc. This means the nutritional decline of wheat grains affects those who depend on them most.

Effect of lower wheat nutrition on rural households

For many rural families, wheat provides a large share of daily calories and protein. Households in the early stages of development tend to consume a high proportion of cereals and coarse grains, which are relatively cheap sources of dietary energy. The main source of fibre in the adult population diet are cereal products (44.1%) followed by vegetables. Only 7.5% of fibre was obtained from whole grain bread, acknowledging once more that consumption of wholegrain cereals could have a significant effect on improvement of public dietary habits. In India, the yearly per capita wheat consumption will increase to 74 kg in 2030 and 94 kg in 2050. This implies that wheat demand will increase by 32–38% in 2030 and 70–104% in 2050 compared to 2019 level of consumption. When nutritional quality declines, it leads to following problems:

- Women and children face increased risk of micronutrient deficiencies, especially iron and zinc. Iron is primarily found in the bran and germ of the wheat kernel, so its removal leads to reduced iron intake. Anemia in pregnant women increases the risk of maternal mortality and poor pregnancy outcomes, while in children, it can lead to fatigue, poor growth, and developmental delays.
- Refined wheat is deficient in essential B vitamins (like folate and thiamine), magnesium, and zinc, all crucial for proper development and immune function. Folate deficiency in women of reproductive age is a major risk factor for neural tube defects in infants.
- Livestock fed with low-protein wheat bran show reduced milk yields and slower growth.
- Variations in nutrient content due to low test-weight or damaged wheat sprout can lead to an unbalanced diet.
- Households spending more on vegetables, pulses, and meat to compensate face higher food bills.

This hidden crisis affects human health, livestock productivity, and farm economics simultaneously.

Climate-smart strategies to mitigate the nutritional crisis

India has several tools to safeguard wheat quality even under climate stress. Some of the strategies are enlisted below:

***Climate-resilient wheat varieties*:** The Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAUs) are continuously engaged in developing climate-resilient wheat varieties capable of withstanding heat and moisture stress while maintaining grain quality. In the context of rising temperatures and increasing frequency of terminal heat stress, these improved cultivars play a critical role in sustaining wheat productivity and farmers' income security. Adoption of zone-specific, stress-tolerant varieties is therefore a key climate adaptation strategy for wheat growers. For early-sown, high fertility conditions, varieties such as DBW 303 (*Karan Vaishnavi*), DBW 187 (*Karan Vandana*), and DBW 327 (*Karan Shivani*) have shown strong tolerance to heat and drought stress. These varieties are particularly suitable where timely sowing and optimal nutrient management practices are followed, ensuring better grain filling and yield stability under elevated temperatures.

Under restricted irrigation or rainfed conditions with timely sowing, several robust options are available. These include UAS 466 (d), DDW 47 (d), HI 8830 (*Pusa Kirti*), DDW 55 (d), CG 1036 (*Vidya*), and HI 1655 (*Pusa Harsha*). These cultivars are specifically bred to perform well with limited water availability, making them highly suitable for water-scarce and drought-prone regions. Their adaptability helps farmers mitigate production risks under uncertain rainfall and constrained irrigation resources. Additionally, HD 3407 (*Unnat* HD 2932) is recognised for its enhanced tolerance to heat stress, particularly terminal heat, thereby supporting yield stability during late-season temperature rise. Overall, strategic varietal selection based on agro-climatic conditions, sowing window, and irrigation availability can significantly enhance resilience, productivity, and profitability in wheat-based cropping systems.

***Better sowing windows*:** Advancing sowing dates by even 7–10 days can help avoid terminal heat. Extension services must guide farmers on region-wise sowing advisories. Early sowing of high yielding wheat varieties enhances productivity and profitability of wheat under rice–wheat cropping system along with lesser noxious impact on the environment. Advancing the sowing time and conservation tillage can improve the productivity of long duration wheat cultivars in sub-tropical humid conditions besides lesser deleterious consequences on the environment.

***Soil nutrient management*:** Soil management strategies enhance nutrient uptake in wheat by improving soil chemical balance, biological activity, and root-soil interactions. Balanced fertiliser use including the adequate supply of macronutrients (Nitrogen, Phosphorous, Potassium) along with micronutrients like zinc and sulphur prevents hidden

deficiencies, optimises enzymatic activity, and supports protein synthesis and chlorophyll formation, thereby sustaining photosynthetic efficiency. Residue retention improves soil organic carbon, enhances cation exchange capacity, moderates soil temperature, and reduces evaporation losses which collectively promote sustained nutrient mineralisation and availability. Application of organic manures further stimulates microbial biomass and activity, enhancing nutrient cycling, chelation of micronutrients, and soil aggregation, leading to improved root proliferation and nutrient absorption. Micro-irrigation systems increase water-use efficiency and maintain optimal soil moisture in the rhizosphere, facilitating mass flow and diffusion of nutrients toward roots while minimising leaching losses. Together, these integrated practices strengthen soil-plant nutrient dynamics, enabling wheat to maintain physiological stability and higher nutrient use efficiency under climatic stress.

Soil moisture conservation: Mulching, zero tillage, and reduced tillage slow down soil drying and protect grain-filling under rising temperatures. Conservation tillage, an alternative crop production system with zero tillage and at least 30% soil surface covered with crop residue, has the potential to address the issues of natural resource degradation, changing climate effects, and shortage of water, energy and labour along with enrichment of soil organic carbon.

Promotion of biofortified wheat: The ICAR, SAUs and CGIAR programmes are working on varieties enriched with zinc, iron, and protein. Adoption of such varieties can help bridge nutrition gaps. About 550 wheat varieties have been released in the country of which 40 varieties, including 10 durum, are biofortified for Fe (>40 ppm), Zn (>40ppm) or protein (>12.0%) based on the established benchmark. The successful release of the first generation of biofortified wheat varieties through dedicated breeding efforts has mainstreamed biofortification in India's wheat improvement programme. Consequently, several biofortified cultivars combining high yield, enhanced nutritional quality, and improved resistance to biotic and abiotic stresses have been released for cultivation across diverse wheat-growing environments. The share of biofortified varieties in breeder seed demand have increased from 4% (2017-18) to 35% (2022-2023) during the period of five years. Varieties like DBW 372, DBW 371, DBW 187, HD 3298, PBW1 *Chapati*, etc. are prominently contributing to this mission of ending hidden hunger and hidden malnutrition.





Released biofortified varieties of wheat

Cropping system alternatives: With the increasing incidence of terminal heat stress affecting wheat during grain filling, adjustment of sowing windows and diversification with short-duration crops can enhance system resilience and farm income stability. When wheat planting is delayed or its duration is strategically shortened to escape high temperature stress, farmers can integrate early-maturing (60–90 days) crops that fit within the altered cropping calendar without compromising resource use efficiency.



Soil moisture conservation through mulching

Suitable alternatives include short-duration pulses such as mungbean and urdbean, oilseeds like mustard (early varieties like Pusa Mustard-25, *Pusa Agrani*, and early lines like RH30) and fodder crops, which possess lower thermal time requirements and higher tolerance to fluctuating temperatures. These crops not only provide an additional income stream but also improve soil health particularly legumes, which contribute biological nitrogen fixation, enhance soil microbial activity, and improve subsequent wheat nutrient availability. Inclusion of such crops in wheat-based systems (e.g. wheat + mungbean or wheat + mustard rotations) increases cropping intensity, optimises residual soil moisture utilisation, diversifies risk under climate variability, and enhances overall system productivity and profitability under changing thermal regimes.

Role of extension: Bridging science and soil

Extension professionals are crucial in ensuring farmers understand not only how climate change affects yields but also how it affects grain nutrition. Demonstrations, advisories, and community-level training can help farmers adopt climate-smart and nutrition-smart practices. Farmers need to know that improving wheat quality is not only a market concern, it is a family nutrition concern. The

extension strategies must shift from a yield-only focus to a dual-objective model of productivity and nutrition. Key strategies include establishing participatory demonstration plots where farmers can witness the performance of biofortified and climate-resilient varieties firsthand, coupled with community-level nutrition workshops that frame wheat quality as a vital component of household health rather than just a market commodity.

SUMMARY

The decline in wheat nutrition may not be visible in the field, but its impact is felt in every household meal. If we do not act now, the hidden hunger crisis will grow silently, affecting the most vulnerable communities. By promoting climate-resilient varieties, smarter agronomy, biofortified wheat, and timely advisories, India can protect not just wheat yields but also the nutritional security of millions of families. The future of wheat is not only about producing more, it is about producing better and healthier wheat in a changing climate.

Extension agents should use the power of timely digital advisory services to provide real-time, site-specific agronomic guidance such as precision nitrogen management and optimal planting windows to mitigate the nutrient-dilution effects of rising temperatures. By nurturing peer-to-peer learning networks and integrating nutritional metrics into standard agricultural training, India can empower its farming communities to adopt 'smarter agronomy' that secures both the quantity and the essential density of the nation's staple food.

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