European Journal of Clinical Pharmacy
Print ISSN: 2385-409X **Online ISSN**: 3105-0409
Website: https://farmclin.com/

Original Research Article

Laser-Based See1d Priming in Wheat: Implications for Grain Bioactive Composition, Food Safety, and Sustainability in Preventive Health

Article History:

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Abstract: Wheat is a principal component of human diets worldwide and a major contributor to dietary fibre, micronutrients, and phytochemicals with established associations to cardiometabolic health when consumed as a whole grain. In clinical pharmacy and public health contexts, upstream agricultural interventions that improve grain quality, reduce chemical inputs, and enhance food safety are increasingly recognised as contributors to disease prevention rather than direct therapy. Laser-based seed priming is a non-chemical, pre-sowing technology that has demonstrated the ability to enhance germination, seedling vigour, and stress tolerance in wheat under adverse environmental conditions. Experimental evidence suggests that low-intensity laser irradiation modulates redox balance, phytohormone signalling, mitochondrial activity, and stress-responsive gene expression, thereby improving crop establishment and yield stability. Several studies further indicate altered phenolic profiles and antioxidant capacity in grains and sprouts, although translation to clinically relevant dietary outcomes remains indirect. This review synthesises current evidence on laser seed priming in wheat, focusing on grain bioactive composition relevant to preventive health, food-safety implications through reduced agrochemical dependence, and sustainability–economic linkages relevant to health-oriented food systems. Methodological limitations, translational gaps, and priorities for clinically relevant research are critically discussed.

Keywords: wheat; whole grains; phenolic compounds; food safety; preventive health; sustainability; laser seed priming; non-chemical agriculture
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Received: 12-01-2026
Revised: 05-02-2026
Accepted: 20-02-2026
Published: 05-03-2026

INTRODUCTION

Diet-related chronic diseases impose a significant burden on healthcare systems worldwide, making food quality and safety crucial factors in determining population health. Wheat (Triticum aestivum L.) is one of the most widely consumed staple crops globally and plays a major role in daily energy intake, dietary fibre, plant protein, and micronutrient supply. When consumed as a whole grain, wheat is associated with a reduced risk of cardiovascular disease, type 2 diabetes, and overall mortality.

The health benefits of wheat are strongly influenced by its grain composition, which includes phenolic acids, flavonoids, tocopherols, and bioactive peptides that possess antioxidant and anti-inflammatory properties (Di Loreto et al 2018, Stuper-Szablewska et al 2019, Zduńska et al 2018). However, grain quality and safety are susceptible to environmental stress, agricultural practices, and chemical inputs, which can alter nutrient profiles and increase dietary exposure to pesticide residues and contaminants (Shekhar et al 2024).

From a clinical pharmacy perspective, interventions that improve the nutritional quality and safety of staple foods—without introducing new chemical agents—are particularly significant. In this context, sustainable agricultural technologies that improve crop resilience and reduce dependence on synthetic inputs can indirectly support preventive health strategies.

Laser-based seed priming has emerged as a physical, non-chemical agricultural technology capable of improving early plant development and stress tolerance. Although primarily researched within agronomy and plant physiology, its potential implications for food quality, sustainability, and public health warrant systematic evaluation in a clinically oriented framework.

From a clinical pharmacy and public health standpoint, food-system interventions that reduce chemical exposure, enhance micronutrient density, and stabilise dietary antioxidant intake are increasingly recognised as cost-effective preventive strategies. Agricultural innovations that influence food quality upstream may therefore contribute indirectly to reduced burden of non-communicable diseases, complementing pharmaceutical prevention approaches.

Aim and Objectives of the Study

The primary aim of this review is to evaluate the effects of laser-based seed priming in wheat as a preventive measure related to food quality, safety, and health, rather than as a direct treatment.

The specific objectives are to:

1. Summarise the current evidence on the physiological, biochemical, and molecular mechanisms through which laser seed priming influences wheat development and grain composition.
2. Assess how the changes induced by laser treatment in phenolic compounds and antioxidant capacity relate to food quality and nutrition-focused health outcomes.
3. Analyse the sustainability and economic implications of laser-based technologies concerning reduced agrochemical use and resource efficiency.
4. Identify translational limitations and research gaps relevant to clinical pharmacy, food safety, and public health nutrition.

2. Methodology

This article is a narrative, integrative review of experimental and applied research on laser seed priming in wheat and related cereal crops.

Literature Sources and Selection

Peer-reviewed articles were identified from journals indexed in Web of Science, Scopus, PubMed, and ScienceDirect, using references provided in the author's compiled bibliography.

Emphasis was placed on studies addressing:

- Laser seed priming or laser-based agricultural technologies;
- Wheat physiology, grain composition, and stress responses;
- Food quality, antioxidant activity, and bioactive compounds;
- Sustainability, agrochemical reduction, and economic outcomes.

Inclusion Criteria:

- Experimental studies (laboratory, greenhouse, and field);
- Reviews and meta-analyses relevant to seed priming, wheat quality, and health-related nutrition;
- Publications reporting mechanistic, compositional, or sustainability-related outcomes.

Exclusion Criteria:

- Studies lacking relevance to wheat or cereal crops;
- Reports focused exclusively on clinical pharmacotherapy without food-system relevance;
- Non-peer-reviewed sources where primary data were unavailable.

No meta-analysis was conducted due to heterogeneity in laser parameters, experimental design, and outcome measures. Findings were synthesised qualitatively, with an emphasis on their relevance to clinical pharmacy and preventive health.

3. Results and Discussion

3.1 Wheat as a Food Matrix Relevant to Preventive Health

Wheat plays a significant role in dietary fibre intake and provides essential micronutrients such as magnesium, zinc, selenium, and B vitamins (Shewry and Hey 2015, Slavin 2004). Consuming whole wheat is consistently associated with better glycemic control, improved lipid metabolism, and reduced systemic inflammation (Aune et al 2016).

The presence of phenolic acids (particularly ferulic acid), flavonoids, and other phytochemicals in wheat offers antioxidant and anti-inflammatory benefits in experimental models (Di Loreto et al 2018, Stuper-Szablewska et al 2019, Zduńska et al 2018). These compounds also help modulate gut microbiota and improve intestinal health, which in turn supports wider metabolic benefits.

Emerging evidence suggests that dietary polyphenols from whole grains can influence oxidative stress, inflammatory pathways, and the composition of gut microbiota. These factors are relevant to cardiometabolic and immune health. Such mechanisms are important in pharmaceutical prevention models, as diet-drug interactions and an individual's baseline nutritional status can alter therapeutic outcomes.

However, it is essential to note that wheat consumption is not risk-free for everyone. Conditions such as celiac disease and non-celiac gluten sensitivity necessitate strict dietary exclusion, highlighting the importance of grain quality, traceability, and safety in food systems (Lebwohl et al 2018, Catassi et al 2015). Therefore, improving wheat quality upstream is crucial for fostering better nutrition and managing risks, particularly for vulnerable populations.

3.2 Environmental Stress, Grain Quality, and Food Safety

Abiotic stresses—including drought, heat, salinity, and nutrient imbalance—significantly impact wheat yields and grain composition (Farooq et al 2009, Munns and Tester 2008, Ismail et al 2017). These stresses can reduce phenolic synthesis, alter protein composition, and compromise grain filling (Asseng et al 2015, Filip et al 2023). Biotic stressors, such as fungal pathogens, further threaten food safety by causing mycotoxin contamination, necessitating the intensive use of fungicides (Savary et al 2019). While chemical control strategies can be effective, they raise concerns about pesticide residues, environmental persistence, and cumulative dietary exposure (Shekhar et al 2024).

Table 1. Key environmental stressors affecting wheat productivity and implications for food quality and public health

Stress category	Main stressors	Agronomic impact	Potential food quality / public health relevance
Abiotic	Drought, heat	Reduced photosynthesis, shortened grain filling, yield loss (Farooq et al 2009, Lobell et all 2012)	Lower micronutrient density; increased food price volatility
Abiotic	Salinity	Impaired nutrient uptake, reduced germination (Munns and Tester 2008)	Reduced mineral content; compromised dietary quality
Abiotic	Nutrient deficiency	Reduced biomass, lower grain protein (Reynolds et al 2005)	Decreased protein intake in staple diets
Abiotic	Waterlogging	Root hypoxia, nutrient leaching	Indirect yield loss affecting food availability
Biotic	Fungal diseases (rusts, *Fusarium*)	Yield loss, mycotoxin contamination [Savary et al 2019]	Food safety risks; increased disease burden
Biotic	Insect pests & viruses	Tissue damage, pathogen transmission	Increased pesticide use; dietary residue exposure
Climate-related	Rising temperature, altered rainfall	Phenological shifts, unstable yields (Zhao et al 2017, Sharma et al 2012)	Threats to food security and preventive nutrition

Technologies that enhance the intrinsic resilience of plants can contribute to safer food systems by reducing dependence on chemical interventions.

3.3 Technologies Enhancing Wheat Resistance

Genetic improvement is a fundamental approach to enhancing wheat resistance. Breeding programs that focus on stress-resilient genotypes target quantitative trait loci associated with drought tolerance, thermal stability, salinity resistance, and pathogen defence (Mao et al., 2023; Afzal et al., 2015). Advances in genomic selection and high-throughput genotyping have accelerated the identification of allelic variants linked to antioxidant capacity, hormonal regulation, and efficient nutrient use (Crossa et al 2017). While these strategies provide durable resistance, their effectiveness can be limited by genotype–environment interactions and the lengthy timelines required for cultivar development. Optimised agronomic practices are crucial for mitigating yield and quality losses caused by stress.

Balanced fertilisation, soil amendments, and precision irrigation enhance nutrient availability, root function, and photosynthetic efficiency under suboptimal conditions (Malko et al 2023, Zhang et al 2018). When properly managed, these interventions can improve grain protein content and yield stability. The excessive use of fertilisers and pesticides can cause significant issues, including nitrate leaching, pesticide residues, and environmental contamination. These problems raise concerns about food safety and public health (Shekhar et al., 2024). To address these challenges, integrated pest management strategies are recommended. These strategies incorporate disease-resistant crop varieties, crop rotation, biological control methods, and targeted chemical applications to reduce disease pressure while minimising the use of chemicals (McDonald 2000). These approaches are increasingly prioritised for their ability to lower dietary exposure to pesticide residues and mycotoxins, aligning with preventive health and regulatory priorities in clinical pharmacy and toxicology. Seed-based physiological conditioning techniques, particularly hydration-based priming, serve as effective pre-sowing strategies to enhance early plant establishment and stress responsiveness (Devika et al 2021, McDonald 2000). Controlled metabolic activation before germination improves antioxidant enzyme activity, hormonal balance, and osmotic adjustment during early growth stages. These physiological adaptations contribute to uniform crop establishment, increased resilience to environmental stress, and reduced reliance on post-emergence chemical interventions.

Table 2. Agronomic stress-mitigation approaches and relevance to clinical pharmacy and public health

Technology	Primary benefit	Limitations	Relevance
Genetic breeding	Durable resistance	Long development time	Indirect preventive benefit
Plant growth regulators	Enhanced growth control	Risk of misuse; variable outcomes	Limited relevance
Seed priming (hydration)	Improved germination	Limited stress scope	Neutral
Plasma/radiation priming	Strong stimulation	Safety and regulation issues	Requires risk assessment

3.4 Laser Seed Priming: Mechanisms and Agronomic Effects

Laser seed priming uses low-intensity coherent light (such as helium-neon lasers) to induce unique photobiological responses that differ from those produced by conventional lighting. Research has shown that this method enhances antioxidant enzyme activity, stabilises the redox balance, modulates phytohormones, and activates stress-responsive genes. (Qiu et al. 2017, Aslam et al 2022, Mardani-Korrani et al 2023, Swathy et al 2021).

These effects contribute to improved germination synchrony, stronger seedling vigour, and increased tolerance to abiotic stresses like drought and salinity. Importantly, laser priming is a non-invasive technique that does not involve the introduction of external chemical agents, aligning with sustainability and food safety priorities.

While laser seed priming does not add bioactive compounds from outside sources, it can enhance the synthesis of beneficial phenolic compounds and boost antioxidant enzyme activity. This positions it as a strategy for optimising food quality rather than a pharmacological intervention. This distinction is crucial in clinical pharmacy, where safety, non-toxicity, and the absence of residual accumulation are key factors in assessing the relevance of treatments.

Table 3. Documented effects of laser seed priming relevant to sustainable food systems

Outcome category	Observed effect	Evidence
Seed performance	Faster germination, improved vigour	(Qiu et al. 2017, Swathy et al. 2021)
Stress resilience	Enhanced drought and salinity tolerance	(Qiu et al. 2017, Swathy et al. 2021, Zrig et al 2022)
Grain composition	Increased phenolics and antioxidants	(Hasan et al 2021, Tsuzuki et al 2017)
Input reduction	Lower fertiliser and pesticide demand	(Koper 1994, Aslam et al 2022, Călinoiu et al 2018)
Food safety	No chemical residues introduced	(Wang et al 2022, Aslam et al 2022)
Health relevance	Improved antioxidant intake potential	(Kumari et al 2019, Shewry et al 2015, Stuper-Szablewska et al 2019, Di Loreto et al 2018)

3.5 Nutritional, Sustainability, and Economic Implications

Multiple studies have shown that laser priming can increase the accumulation of phenolic compounds and antioxidants in grains and sprouts (Aslam et al 2022, Zrig et al 2022). While these changes do not necessarily enhance therapeutic effects, they may contribute to improved dietary antioxidant intake at a population level.
Laser-based technologies have shown promise in enhancing yield stability while reducing the need for fertilisers,

water, and pesticides across various regions (Podlesny et al 2001). These efficiencies help lower environmental burdens and decrease chemical exposure in food supply chains.

From a public health perspective, laser seed priming supports a "triple-benefit" framework:
- Economic - improved productivity and cost efficiency;
- Environmental - reduced use of agrochemicals and water;
- Health-related - enhanced food safety and nutritional consistency.

A decreased reliance on synthetic fertilisers and pesticides has direct implications for public health, including lower dietary exposure to chemical residues and reduced contamination of water resources. These outcomes align with preventive healthcare strategies that emphasise the environmental determinants of disease and aim to lower healthcare costs associated with chronic exposure to agrochemicals.

Table 4. Economic, sustainability, and health-related outcomes of laser-based technologies by country

Country	Technology	Key benefit	Sustainability & health relevance
Poland	Laser seed priming	↑ Yield, ↓ N fertiliser	Reduced nitrate pollution
Bulgaria	Laser seed priming	Improved emergence	Stable food production
France	Advanced seed treatments	↓ Water & fertiliser use	Lower environmental exposure
Spain / Denmark	Laser weed control	↓ Herbicide use	Reduced food residues
India	Laser land levelling	↑ Yield, ↑ income	Water conservation
China	Laser levelling + seeding	↑ Efficiency	Resource optimisation
Pakistan	Laser land levelling	↓ Irrigation demand	Food security
Mexico	Laser biostimulation	Improved crop vigour	Reduced agrochemical dependence

Laser-based seed priming is not a therapeutic intervention; however, it serves as a preventive measure that positively impacts food composition, safety, and sustainability.
Its relevance to clinical pharmacy includes the following points:
(i) Reduction of pesticide and nitrate residues in staple foods.
(ii) Stabilisation of antioxidant intake across populations.
(iii) Enhanced resilience of food supply chains under climate stress.
These upstream interventions complement pharmaceutical prevention by addressing environmental and dietary risk factors before the disease onset. This approach emphasises the importance of sustainable food systems within integrated healthcare models, aligning with current trends in clinical pharmacy that focus on population-level prevention and One Health frameworks.

Table 5. Clinical pharmacy relevance of laser seed priming as an upstream preventive intervention

Dimension	Contribution of laser seed priming
Pharmacological role	Non-therapeutic
Prevention level	Primary / population-level
Exposure reduction	↓ Pesticide and fertiliser residues
Nutritional impact	Stabilised antioxidant intake
Safety profile	Non-toxic, residue-free
EJCP relevance	Environmental determinants of health

3.6 Limitations and Translational Considerations
Evidence remains largely experimental, with limited standardisation of laser parameters and few long-term field-scale studies. No controlled human dietary trials have evaluated health outcomes related to the consumption of laser-primed wheat products.

Accordingly, laser seed priming should be viewed as a food-system optimisation strategy rather than a clinical intervention. Further research should prioritise compositional analysis, contaminant profiling, and exposure-based risk assessment.

4. Conclusion
Laser-based seed priming is a sustainable, non-chemical agricultural technology that has important indirect implications for clinical pharmacy and public health. By enhancing wheat's resilience to stress, stabilising yields, and improving the

antioxidant composition of grains, laser priming contributes to food systems that emphasise nutritional quality, safety, and environmental sustainability.

This technology supports preventive health strategies by decreasing the reliance on agrochemicals, which in turn reduces dietary exposure to harmful residues and stabilises intake of bioactive food compounds. Although direct clinical outcomes have not yet been evaluated, the upstream benefits of laser priming align with prevention strategies in pharmacy that emphasise reducing modifiable environmental and dietary risk factors.

Funding
The study was funded by the project titled "Quantitative and Qualitative Evaluation of Phenolic Compounds in Grain Germinates and Grass Seedlings of Wheat Processed with Innovative Laser Bioagrotechnology to Develop a Functional Health-Improving Drug." This project is supported by Grant Agreement No. FR-22-6966, dated March 9, 2023, and is funded by the Shota Rustaveli National Science Foundation of Georgia as part of the 2022 state scientific grants competition.

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