SEED TECHNOLOGY

Seed Production and Technology in Wheat: Genetic Purity, Quality Assurance, Processing and Storage

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Abstract

Seed is a fundamental agricultural input because it carries the genetic potential of a crop variety and strongly influences crop establishment, uniformity and productivity. Quality wheat seed requires coordinated management of genetic purity, physical purity, physiological quality and seed health from source-seed maintenance through field multiplication, inspection, harvesting, processing, testing, packaging and storage. Wheat is predominantly self-pollinated, but varietal identity can still be compromised by off-types, volunteer plants, mechanical mixtures and seed-associated pathogens. This review synthesizes classical seed-production principles with recent evidence on wheat seed systems, seed vigour, storage, seed health and emerging analytical technologies. Particular emphasis is placed on preventive field quality control, representative sampling, validated testing, careful processing and storage. Recent studies show that storage environment and packaging can substantially affect wheat seed viability and that non-destructive imaging and molecular approaches offer opportunities for more rapid quality assessment. An integrated, standards-based approach can therefore strengthen varietal identity, physiological quality, traceability and seed performance across the wheat seed chain.

Keywords: genetic purity; seed health; seed processing; seed production; seed quality; seed storage; seed systems; seed testing; seed vigour; Triticum aestivum L; wheat

1 Introduction

Seed is the basic biological input through which the genetic potential of a crop variety is transferred from one generation to the next. In wheat, a predominantly self-pollinated crop, formal seed systems use successive multiplication stages to maintain varietal identity and distribute improved cultivars. Wheat seed systems commonly involve nucleus, breeder, foundation and certified classes, although terminology and regulatory arrangements vary among countries (Joshi and Braun, 2022).

Seed quality is multidimensional. Genetic quality concerns varietal identity and genetic purity; physical quality concerns pure seed and freedom from undesirable materials; physiological quality includes germination, vigour and longevity; and seed health concerns the occurrence of seed-associated pathogens. Recent work also highlights the interaction between production environment, seed vigour and subsequent crop establishment (Marinho et al., 2021; Souza et al., 2021).

2 Seed quality and seed testing

Representative sampling is fundamental to seed testing because a laboratory result is useful only when the test sample adequately represents the seed lot. The ISTA Rules provide standardized

procedures for sampling, testing and reporting seed-lot quality, with the 2026 edition effective from 1 January 2026 (ISTA, 2026).

Physical purity analysis separates pure seed from other crop seed, weed seed and inert matter. Physiological quality is commonly assessed through germination and vigour-related tests, whereas seed-health testing uses validated methods appropriate to the pathogen or health attribute being investigated. Genetic purity may be assessed through field inspection, grow-out testing and, where validated and appropriate, biochemical or molecular methods. The components of wheat seed quality and their assessment are summarized in Table 1.

Table 1. Major components of wheat seed quality and representative assessment approaches.

Quality component	What it indicates	Representative assessment	Main quality-control stage
Genetic purity	Varietal identity and trueness-to-type	Field inspection; grow-out testing; validated molecular methods	Source seed, field multiplication, post-harvest verification
Physical purity	Pure seed and freedom from contaminants	Purity analysis; separation and grading	Harvesting, cleaning, processing
Physiological quality	Germination, vigour and viability	Standard germination; vigour tests; ageing-related tests	Maturity, drying, processing, storage
Seed health	Presence/absence of relevant pathogens	Validated seed-health tests	Field production, seed treatment, laboratory testing
Moisture/storage quality	Risk of deterioration during storage	Moisture determination; storage monitoring	Drying and storage

3 Genetic purity and nucleus seed maintenance

Genetic purity is the foundation of varietal identity. Maintenance breeding involves selection of true-to-type material and controlled multiplication so that varietal characteristics are retained across generations. In wheat seed systems, early-generation seed is especially important because any impurity introduced early can be multiplied during subsequent generations (Joshi and Braun, 2022).

Nucleus seed is a small quantity of highly pure seed maintained under breeder or institutional supervision. The exact number of plants or ear heads selected, progeny design and generation nomenclature should follow the relevant institutional protocol rather than being treated as universal values. Field selection, progeny evaluation and removal of off-types are central preventive measures.

Molecular approaches can complement conventional phenotypic assessment where validated. The broader seed-quality literature identifies molecular marker technologies as increasingly relevant for varietal identity, genetic purity and pathogen detection (Seed Quality, 2022).

4 Field selection, previous cropping and isolation

Seed-production fields should be suitable for wheat, reasonably uniform, well drained and free from problematic volunteer plants and weeds. Previous cropping history is important because volunteer plants and crop residues may create opportunities for varietal admixture or disease carry-over. Field and land requirements should be applied according to the current crop-specific certification standard.

Isolation reduces the risk of varietal admixture. Although wheat is predominantly self-pollinated, limited out-crossing and mechanical admixture remain relevant quality risks. The applicable isolation distance, permissible off-type limits and inspection requirements should be taken from the current Indian seed-certification framework for the particular seed class rather than generalized across all production situations.

5 Sowing and crop establishment

Sowing date, seed rate and row spacing should be selected according to variety, sowing window, soil, irrigation availability and locally recommended agronomy. A uniform row arrangement facilitates crop management, inspection and rouging. Seed drills and handling equipment should be cleaned thoroughly before changing varieties or seed lots to reduce mechanical admixture.

Seed vigour also influences establishment. Experimental evidence indicates that high-vigour seed can improve stand establishment, particularly under less favourable environmental conditions, although the effect depends on environment, cultivar and crop-management factors (Marinho et al., 2021).

6 Nutrient and water management

Balanced nutrient management is necessary for healthy crop growth and adequate seed development. Fertilizer recommendations should be based on soil fertility, crop requirement, expected yield and locally validated recommendations. Research has shown that nitrogen management and environmental conditions can influence both crop performance and the physiological quality of harvested wheat seed (Souza et al., 2021).

Irrigation requirements vary with soil type, weather, sowing date and variety. Therefore, fixed irrigation counts should not be presented as universal recommendations. Irrigation should be scheduled using local agronomic recommendations and crop-water requirements, with attention to moisture-sensitive stages.

7 Rouging and field inspection

Rouging is the systematic removal of undesirable plants from a seed-production field. Off-types may differ in plant height, leaf characteristics, spike morphology, flowering behaviour, maturity and other diagnostic characters. More than one rouging operation may be required because varietal differences become visible at different developmental stages.

Field inspection is a preventive quality-control measure. It should be complemented by post-harvest seed-lot testing where required. The combination is stronger than reliance on laboratory testing alone because contamination that occurs during crop growth cannot be fully corrected after harvest.

8 Disease and seed health management

Seed health is an important component of seed quality because seed-associated pathogens can contribute to disease establishment and dissemination. Wheat seed can be associated with fungal pathogens, including smuts and bunts and seed-health risks vary with pathogen biology, cultivar, environment and production system.

Management should integrate field sanitation, suitable cultivar choice, crop management, disease monitoring, appropriate seed treatment and validated laboratory testing. For loose smut, for example, seed-associated infection is an important epidemiological consideration and management commonly integrates resistant cultivars and appropriate seed treatment (Abrahim, 2019). The ISTA Rules provide a standardized framework for seed-health testing methods, with Chapter 7 addressing seed-health testing (ISTA, 2026). Selected seed-health risks and management responses are summarized in Table 2.

Table 2. Selected seed-health risks in wheat and quality-management responses.

Risk / group	Quality concern	Management emphasis	Testing / verification
Loose smut and other smuts	Seed-associated infection and disease transmission	Resistant cultivars; appropriate seed treatment; clean seed production	Validated seed-health methods where applicable
Bunts	Seed/grain contamination and quality loss	Clean seed; field sanitation; appropriate treatment according to label/recommendation	Pathogen-specific testing where required
Seed-associated fungi	Reduced seed quality or emergence; possible storage problems	Drying, sanitation, suitable treatment and storage	Validated seed-health assessment
Storage fungi	Deterioration under high moisture/humidity	Safe drying; humidity and temperature management	Moisture and storage monitoring

9 Harvesting, threshing and seed processing

Harvesting should be timed to minimize weather damage, shattering and mechanical injury. A single grain-moisture value should not be treated as a universal harvesting threshold because suitable moisture depends on harvest equipment, environmental conditions and subsequent drying capacity. Seed intended for storage must subsequently be dried to a level appropriate for the seed, package and storage environment.

Cleaning and grading remove undesirable materials and improve lot uniformity. Common processing equipment includes pre-cleaners, air-screen cleaners and specialized separators such as length or gravity separators. Processing equipment should be correctly adjusted and cleaned between lots to minimize admixture and mechanical damage. The main processing operations and their quality objectives are listed in Table 3.

Table 3. Wheat seed processing operations and quality objectives.

Operation	Primary objective	Key quality risk	Control point
Pre-cleaning	Remove large/light foreign material	Loss of good seed or incomplete separation	Correct screen/air settings
Air-screen cleaning	Separate seed from impurities by size and aerodynamic properties	Mechanical damage or poor separation	Equipment adjustment and calibration
Length separation	Separate materials with different length characteristics	Incomplete separation	Appropriate cylinder/ indenter settings
Gravity separation	Separate fractions by density	Loss of viable seed if settings are excessive	Correct feed and airflow

Operation	Primary objective	Key quality risk	Control point
Grading	Improve lot uniformity	Over-processing or seed injury	Size specifications and gentle handling
Final clean-out	Prevent lot-to-lot admixture	Residual seed contamination	Thorough equipment clean-out

10 Seed treatment and packaging

Seed treatment is used where appropriate to protect seed and seedlings against specified pathogens. Treatment choice should be based on target organism, seed condition, disease risk and currently approved local recommendations. Uniform application and correct dose are essential.

Packaging protects seed from moisture, contamination and physical damage and should comply with applicable certification and labeling requirements. Lot identity and traceability should be maintained from processing through distribution.

11 Seed storage and physiological quality

Storage aims to preserve germination, vigour and viability achieved during production and processing. Temperature, seed moisture, packaging and storage duration interact to determine deterioration. A 2025 study of wheat seed reported better preservation under controlled temperature and showed that packaging and storage environment strongly affected viability and deterioration-related biochemical indicators (Shafat et al., 2025).

Independent evidence also indicates that hermetic storage can preserve wheat seed germination better than conventional polyethylene-based storage under humid seasonal conditions in smallholder systems (Gathala et al., 2022). Long-term conservation research further demonstrates the importance of storage temperature: wheat samples maintained at −20 °C retained substantially higher germination than samples stored at 4 °C over multi-decadal periods (van Treuren et al., 2018).

High seed moisture and elevated temperature generally accelerate deterioration. Storage management should therefore include appropriate drying, moisture monitoring, protection against insects and rodents and regular assessment of seed quality. The major storage factors affecting seed longevity are summarized in Table 4.

Table 4. Major storage factors affecting wheat seed longevity.

Factor	Likely effect on seed quality	Management implication	Recent evidence
Seed moisture	Higher moisture generally accelerates deterioration and fungal risk	Dry seed appropriately before storage; monitor moisture	Goglia et al., 2026; Shafat et al., 2025
Temperature	Higher temperature generally accelerates ageing	Use suitable cool storage where feasible	van Treuren et al., 2018; Shafat et al., 2025
Packaging	Controls moisture exchange and physical protection	Select packaging according to storage environment and duration	Gathala et al., 2022; Shafat et al., 2025
Relative humidity	High humidity can raise seed moisture	Maintain dry storage conditions	Gathala et al., 2022

Factor	Likely effect on seed quality	Management implication	Recent evidence
Storage duration	Progressive loss of vigour/viability	Monitor germination and vigour periodically	Shi et al., 2020; Shafat et al., 2025

12 Modern approaches to seed quality assessment

Recent research is expanding seed testing beyond conventional visual and laboratory methods. Hyperspectral imaging has been investigated for non-destructive prediction of wheat seed germination, germination energy and vigour during storage (Zhang et al., 2020). Such approaches may support rapid screening, although their adoption for official certification requires validation and conformity with applicable testing frameworks.

Genetic and molecular approaches can also support variety identification and genetic-purity assessment. Their main advantage is the ability to examine genetic differences directly rather than relying only on environmentally influenced morphological characters. However, molecular results should be interpreted within validated protocols and should complement rather than automatically replace regulatory field and seed testing.

Recent seed research also emphasizes biological and molecular mechanisms underlying longevity and seed–microbe interactions, opening opportunities for improved prediction of seed ageing and seed-health management (Das and Majee, 2026; Singh et al., 2026). Emerging technologies relevant to seed quality assurance are summarized in Table 5.

Table 5. Emerging technologies relevant to wheat seed quality assurance.

Technology	Potential application	Advantage	Current limitation / requirement
Hyperspectral imaging	Rapid, non-destructive assessment of germination/ vigour-related attributes	High-throughput screening potential	Calibration and independent validation required
DNA markers / molecular assays	Variety identification and genetic-purity assessment	Direct genetic information; less affected by environment	Validated marker sets and regulatory acceptance required
Digital traceability	Lot identity and movement tracking	Improves traceability and accountability	Infrastructure and data standards required
AI-assisted image analysis	Automated seed/plant classification and testing support	Potentially rapid and scalable	Training data, validation and error control required
Seed microbiome approaches	Seed health and beneficial-microbe research	May improve understanding of seed–microbe interactions	Field-level standardization and validation are still developing

13 Integrated seed quality management

Quality wheat seed production is an integrated chain rather than a set of independent operations. Genetic purity begins with authentic source material and is protected through maintenance, field selection, isolation and rouging. Physical purity is maintained through harvesting and processing. Physiological quality is protected through suitable maturity management, drying and storage, while seed health is managed through field disease prevention, testing and appropriate treatment.

The integrated quality-management pathway is shown in Figure 1.

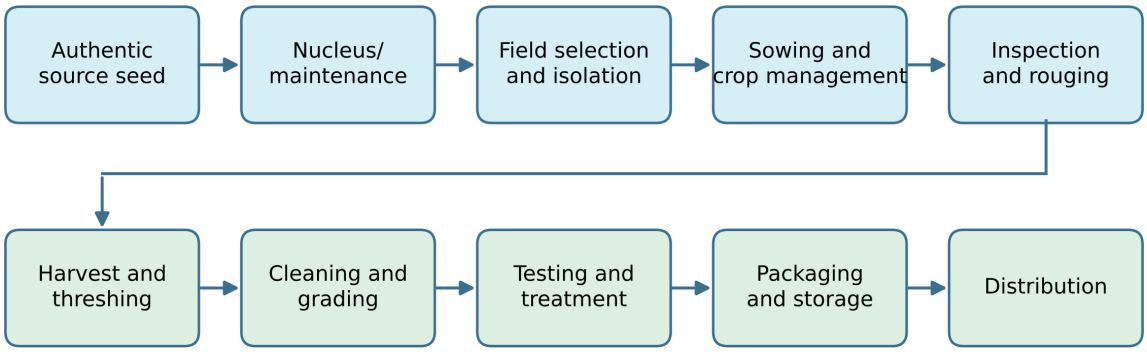


Figure 1. Integrated wheat seed quality-management pathway.

The pathway emphasizes preventive control: source identity is protected before multiplication, field contamination is minimized before harvest and seed-lot quality is verified through representative sampling and appropriate testing before storage and distribution. Current ISTA rules provide standardized procedures for sampling and seed testing, while national certification requirements govern official acceptance criteria (ISTA, 2026).

14 Future perspectives

Future wheat seed systems will increasingly combine conventional field-based quality control with standardized laboratory testing, improved traceability and validated digital or molecular tools. Wheat seed-system research emphasizes the need to strengthen early-generation multiplication and accelerate dissemination of improved varieties while maintaining seed quality (Joshi and Braun, 2022).

Advances in storage science, imaging, molecular diagnostics and seed microbiome research may improve prediction and management of seed quality. Nevertheless, emerging technologies should be validated against established reference methods and incorporated into certification systems only where their accuracy, repeatability and operational value are demonstrated.

15 Conclusion

Quality wheat seed production begins with authentic genetic material and continues through controlled multiplication, field selection, isolation, crop management, rouging, inspection, harvesting, processing, testing, treatment, packaging and storage. Genetic purity, physical purity, physiological quality and seed health should be managed together because deterioration at one stage can compromise quality achieved at earlier stages.

Recent evidence reinforces the importance of seed vigour, storage environment, packaging and improved testing technologies. An integrated approach based on current certification standards, representative sampling, validated testing and careful post-harvest management provides a practical framework for maintaining varietal identity and seed performance. Specific regulatory limits and certification procedures should always be taken from the current applicable national standards.

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