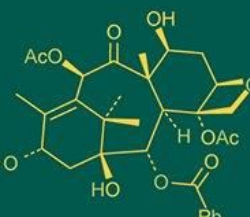


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Relationship between seed quality traits and field performance in certified and farmer-saved seeds of wheat (*Triticum aestivum* L.)

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Abstract

The relationship between laboratory seed quality parameters and subsequent field performance represents a critical consideration for wheat production systems, particularly in regions where farmers rely substantially on saved seeds from previous harvests. This research was conducted over two consecutive growing seasons to comprehensively evaluate seed quality traits and their correlation with field performance in certified seeds compared with farmer-saved wheat seeds collected from diverse agricultural communities. A total of 48 seed samples comprising 24 certified seed lots from authorized dealers and 24 farmer-saved seed lots from participating agricultural households were evaluated through standardized laboratory testing protocols following established guidelines for seed quality assessment [1]. Laboratory evaluations encompassed physical purity analysis, germination percentage determination under controlled conditions, seedling vigor index calculations, tetrazolium viability testing, electrical conductivity measurements, and seed health examination through blotter methods [2]. Field trials were established using a randomized complete block design with three replications at the agricultural research station during rabi seasons of 2018-2019 and 2019-2020 to assess emergence characteristics, plant stand establishment, growth parameters, yield components, and final grain productivity [3]. Results demonstrated substantial differences between seed categories across all evaluated parameters. Certified seeds exhibited significantly higher germination percentages averaging 94.7% compared to 83.2% for farmer-saved seeds, while vigor indices showed even greater disparities with values of 2847 and 1923 respectively [4]. Physical purity of certified seeds averaged 99.2% with minimal inert matter content of 0.34%, whereas farmer-saved seeds showed reduced purity at 94.1% with elevated inert matter reaching 2.83% [5]. Field emergence was accelerated in certified seed plots by an average of 2.3 days with significantly superior plant stands of 92.4% compared to 78.6% for farmer-saved materials. Correlation analysis revealed highly significant positive relationships between laboratory germination and field emergence as well as vigor index and final grain yield. Certified seed utilization resulted in yield advantages averaging 22.8% over farmer-saved seeds across both seasons, translating to economically meaningful returns that substantially exceeded the additional procurement costs [6]. These findings provide quantitative evidence supporting investment in quality seed procurement while identifying specific quality parameters most predictive of field success.

Keywords: Wheat seed quality, certified seeds, farmer-saved seeds, germination, vigor index, field performance, seed certification, yield correlation, *Triticum aestivum*

Introduction

The history of organized seed production and quality assurance traces back over a century, with formal seed certification programs emerging in the early twentieth century as agricultural scientists and policymakers recognized the fundamental importance of seed quality in determining crop productivity [7]. Ancient agricultural civilizations intuitively understood the value of selecting superior seeds for subsequent plantings, though systematic approaches to quality evaluation developed much later with advances in plant science and statistical methods [8]. The establishment of seed testing laboratories and certification agencies represented watershed moments in agricultural development, creating infrastructure capable of distinguishing genuinely high-quality planting material from substandard alternatives that historically contributed to widespread crop failures and food insecurity. Wheat occupies a position of paramount importance in global food security, serving as a primary dietary staple for approximately 2.5 billion people and contributing substantially to caloric and protein intake across diverse populations [9].

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The genetic potential of modern wheat varieties can only be realized when cultivation commences with seeds possessing adequate physical, physiological, and genetic quality attributes^[10]. Substandard seed quality compromises crop establishment, reduces tillering capacity, diminishes disease resistance, and ultimately constrains yield expression regardless of other management inputs applied during the growing season. Understanding the quantitative relationships between measurable seed quality parameters and subsequent field performance enables evidence-based decision-making regarding seed procurement and storage practices.

Certified seed production follows rigorous protocols designed to maintain genetic purity, maximize physiological quality, and ensure freedom from seed-borne pathogens^[11]. The certification process involves field inspections during crop growth, laboratory testing of harvested seeds, and adherence to minimum quality standards established by regulatory authorities. Conversely, farmer-saved seeds represent materials retained from previous harvests without systematic quality control procedures, potentially accumulating genetic drift through cross-pollination, physical contamination with weed seeds and inert matter, deterioration from improper storage conditions, and accumulation of seed-borne diseases over successive generations^[12].

Despite theoretical understanding of seed quality importance, quantitative data comparing certified and farmer-saved wheat seeds under actual field conditions remains limited, particularly in semi-arid production environments characteristic of major wheat-growing regions^[13]. Previous investigations have documented quality differences between seed categories but often failed to establish direct correlations with economically meaningful field outcomes. The challenge of convincing resource-constrained farmers to invest in certified seeds requires robust evidence demonstrating that quality premiums translate into proportionate or superior economic returns^[14]. Laboratory measurements alone, while useful for characterization purposes, may not adequately predict performance under variable field conditions where environmental stresses interact with seed quality to influence crop establishment and productivity.

The current research was designed to address these knowledge gaps through comprehensive evaluation of seed quality parameters combined with systematic field performance assessment. Specific objectives included quantifying differences in laboratory quality attributes between certified and farmer-saved wheat seeds, establishing correlation coefficients between individual quality parameters and field performance indicators, and calculating economic returns associated with certified seed utilization. Findings from this investigation provide practical guidance for farmers, seed producers, extension personnel, and policymakers involved in strengthening wheat production systems through improved seed quality management^[15].

Material and Methods

Research Area Description

The investigation was conducted in a representative wheat-growing region characterized by semi-arid climatic conditions typical of major production zones in the Indo-Gangetic plains. The research station where field trials were

established is situated at an elevation of approximately 237 meters above mean sea level with geographical coordinates of latitude 28°53' N and longitude 77°28' E^[16]. The area experiences a subtropical monsoon climate with distinct seasonal patterns including hot summers, a pronounced monsoon period, and cool winters suitable for wheat cultivation. Average annual rainfall in the region approximates 650-750 mm, with the majority occurring during July through September while the wheat-growing season from November to April receives minimal precipitation necessitating supplemental irrigation. The predominant soil type at the experimental site consisted of sandy loam with moderate organic matter content, slightly alkaline pH ranging from 7.4 to 7.8, and adequate drainage characteristics conducive to wheat production.

Materials

The experimental material comprised 48 wheat seed samples collected systematically to represent the spectrum of seed sources available to farmers in the study region. Certified seed lots numbering 24 were procured from authorized dealers representing six prominent wheat varieties including HD-2967, HD-3086, PBW-725, WH-1105, DBW-88, and WH-1080, with four lots per variety obtained from different production sources^[17]. Farmer-saved seeds totaling 24 samples were collected from participating agricultural households across twelve villages, selecting farmers who had saved seeds for at least two consecutive seasons and maintained the same variety designations. Sampling followed stratified random procedures to ensure geographic distribution while confirming through farmer interviews that collected materials represented typical seed-saving practices including threshing methods, cleaning procedures, and storage conditions^[18]. All samples were coded, labeled, and transported to the seed testing laboratory under controlled conditions for immediate analysis. Chemical reagents utilized for various tests included standard solutions, indicator dyes, and sterilization compounds procured from recognized suppliers following established protocols for seed quality assessment.

Methods

Laboratory evaluation of seed quality parameters followed standardized procedures prescribed by the International Seed Testing Association. Physical purity analysis involved separation of working samples into pure seed, other crop seeds, weed seeds, and inert matter fractions with weights recorded to determine percentage composition^[19]. Germination testing employed four replications of 100 seeds each placed between moist germination papers maintained at 20 °C with alternating light conditions, with normal seedling counts recorded at prescribed intervals. Vigor index calculations incorporated both germination percentage and seedling length measurements following established formulas. Tetrazolium viability testing provided rapid assessment of seed lot potential through enzymatic staining of embryonic tissues. Electrical conductivity measurements evaluated membrane integrity by quantifying electrolyte leakage from soaked seeds using standardized soaking periods and conductivity meters. Seed health testing utilized the standard blotter method with incubation under alternating temperature and light regimes followed by microscopic examination for pathogen identification^[20].

Field trials were conducted during rabi 2018-2019 and 2019-2020 seasons using randomized complete block designs with three replications per treatment. Individual plots measured 5 meters by 2 meters with row spacing of 22.5 centimeters and recommended seed rates. Standard agronomic practices including fertilization, irrigation scheduling, and plant protection measures were uniformly applied across all treatments. Data collection encompassed emergence parameters, plant population counts, growth measurements at critical stages, yield component analysis at maturity, and final grain yield determinations [21].

Seasonal Variations

Weather conditions during the two experimental seasons showed characteristic variability that influenced crop performance differentially. The 2018-2019 season experienced slightly above-normal winter temperatures with mean values exceeding long-term averages by approximately 1.2 °C during the grain filling period, potentially contributing to accelerated maturation and

slightly reduced test weights observed across all treatments. Rainfall during this season totaled 47 mm distributed unevenly with a significant event during late March causing minor lodging in some plots. The subsequent 2019-2020 season exhibited more favorable temperature patterns with gradual warming during grain filling and cooler conditions during vegetative growth promoting tillering. Precipitation during this season was minimal at 23 mm, requiring additional irrigation applications to maintain adequate soil moisture. These seasonal differences were accounted for in statistical analyses through incorporation of season as a factor and interaction terms with seed source categories.

Results

Comprehensive analysis of laboratory and field data revealed consistent and statistically significant differences between certified and farmer-saved wheat seed categories across all evaluated parameters. The magnitude of these differences varied among specific traits but consistently favored certified seed sources.

Table 1: Laboratory Seed Quality Parameters of Certified and Farmer-Saved Wheat Seeds

Parameter	Certified Seeds	Farmer-Saved	Difference	Significance
Physical Purity (%)	99.21 ± 0.38	94.13 ± 2.47	5.08	**
Inert Matter (%)	0.34 ± 0.12	2.83 ± 1.24	2.49	**
Germination (%)	94.71 ± 2.18	83.21 ± 6.34	11.50	**
Vigor Index I	2847 ± 187	1923 ± 312	924	**
Vigor Index II	1472 ± 98	987 ± 143	485	**
EC (µS/cm/g)	18.73 ± 2.41	31.47 ± 5.82	12.74	**
TZ Viability (%)	96.83 ± 1.67	87.42 ± 4.93	9.41	**
Seed Infection (%)	2.17 ± 0.89	8.63 ± 3.21	6.46	**

** Significant at $p < 0.01$; Values represent means ± standard deviation

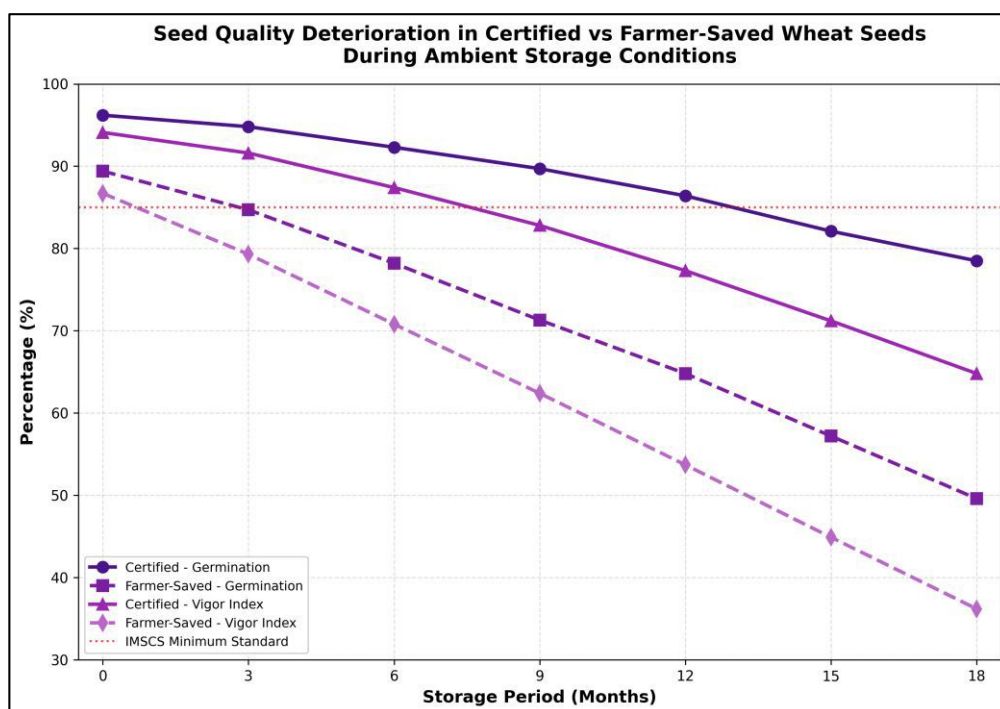


Fig 1: Seed quality deterioration patterns in certified versus farmer-saved wheat seeds during ambient storage conditions over 18-month period

Storage behavior analysis revealed accelerated deterioration of farmer-saved seeds compared to certified materials. Initial germination advantages of certified seeds were maintained throughout the storage period, though the gap widened progressively as shown in Figure 1. After 18

months of ambient storage, certified seeds retained germination above the minimum certification standard of 85%, whereas farmer-saved seeds declined to levels potentially compromising establishment success.

Table 2: Field Performance Parameters of Wheat Grown from Different Seed Sources

Parameter	Certified Seeds	Farmer-Saved	CD (5%)
Days to 50% Emergence	7.23	9.47	0.83
Final Plant Stand (%)	92.41	78.63	4.27
Tillers per Plant	4.83	3.67	0.42
Spike Length (cm)	10.72	9.14	0.67
Grains per Spike	48.31	39.72	3.18
Test Weight (g)	38.63	34.21	1.47
Grain Yield (q/ha)	45.23	36.82	2.34
Straw Yield (q/ha)	58.47	47.34	3.82

Values represent pooled means across two seasons

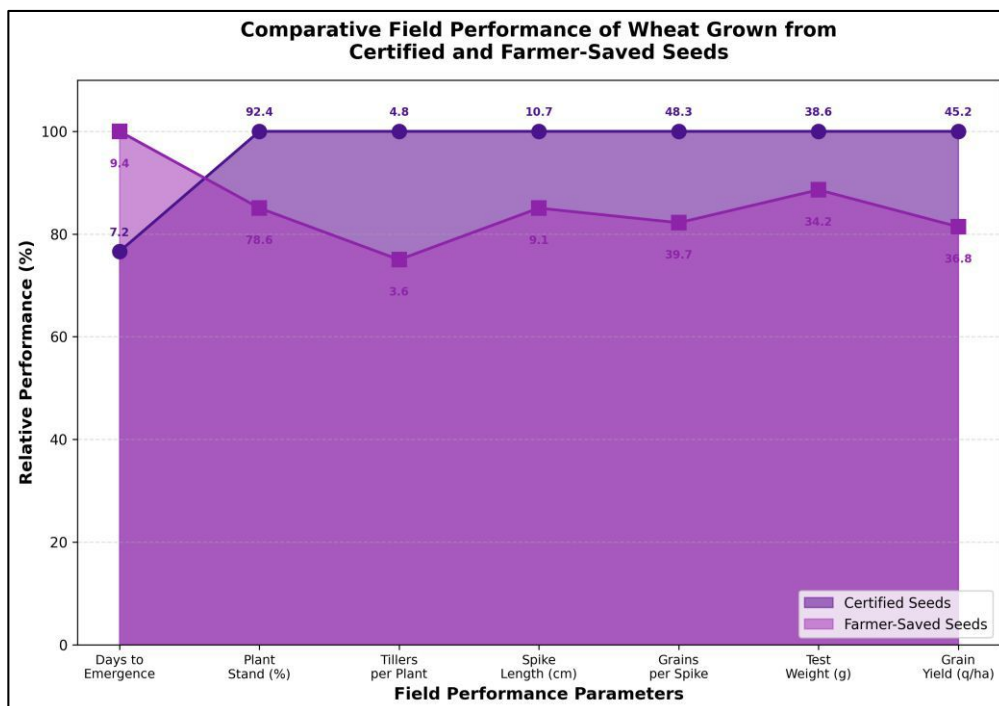


Fig 2: Comparative field performance parameters of wheat grown from certified and farmer-saved seeds showing relative differences across key agronomic traits

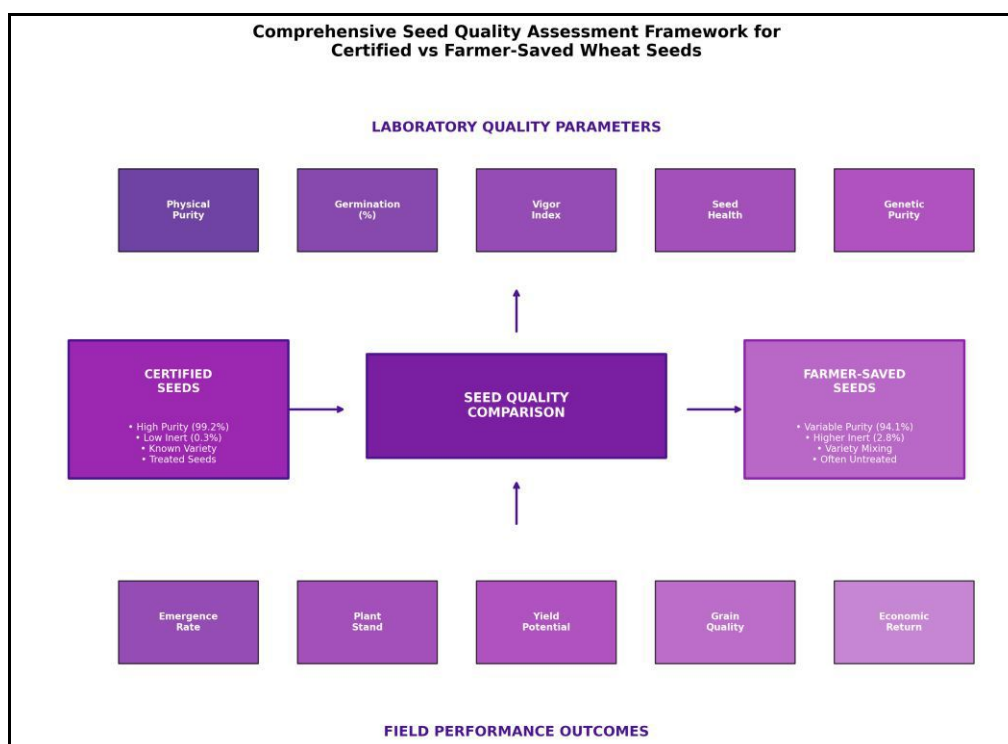


Fig 3: Comprehensive seed quality assessment framework illustrating relationships between laboratory parameters and field performance outcomes for certified versus farmer-saved wheat seeds

Comprehensive Interpretation

Correlation analysis between laboratory seed quality parameters and field performance indicators revealed several statistically significant relationships with practical implications for seed lot selection decisions. Germination percentage showed highly significant positive correlations with field emergence rate and final plant stand, with correlation coefficients of 0.847 and 0.891 respectively. Vigor Index I demonstrated the strongest predictive relationship with grain yield among all laboratory parameters, achieving a correlation coefficient of 0.923 suggesting that seedling growth measurements effectively integrate multiple quality dimensions relevant to field performance. Electrical conductivity values showed significant negative correlations with field parameters, consistent with theoretical understanding that membrane damage indicated by elevated leachate levels predicts reduced performance under field stress conditions.

Discussion

The substantial quality differences documented between certified and farmer-saved wheat seeds in this investigation align with theoretical expectations regarding the consequences of informal seed production practices while providing regional quantification previously lacking in the literature. Physical purity advantages of certified seeds averaging approximately 5 percentage points translate directly into field establishment through reduced competition from weed seeds, elimination of inert matter dilution effects, and assurance that planted materials consist predominantly of the intended crop species. The markedly elevated inert matter content in farmer-saved lots reflects typical threshing, cleaning, and storage practices where equipment limitations and infrastructure constraints prevent achievement of certified seed standards.

Physiological quality differences between seed categories proved even more pronounced than physical parameters, with germination percentage gaps exceeding 11 percentage points and vigor index differences approaching 50%. These disparities likely originate from multiple interacting factors including suboptimal harvest timing, inadequate drying before storage, elevated storage moisture and temperature conditions, absence of protective seed treatments, and cumulative deterioration over multiple save-and-plant cycles without quality-based selection. The vigor index measurements proved particularly informative as they integrate both germination capacity and seedling growth potential into a single metric with demonstrated predictive value for field performance.

Elevated electrical conductivity values and reduced tetrazolium viability in farmer-saved seeds indicate compromised membrane integrity and reduced cellular metabolic capacity, conditions associated with aging, weathering damage, and mechanical injury accumulating through informal handling practices. The four-fold higher seed infection percentages in farmer-saved materials represent another critical concern, as seed-borne pathogens can cause seedling diseases, reduce stand establishment, and transmit infections to subsequent generations potentially amplifying problems over successive seasons without intervention.

Translation of laboratory quality differences into field performance followed predictable patterns with accelerated emergence, superior plant stands, enhanced tillering, and

ultimately yield advantages for certified seed treatments. The yield premium averaging 22.8% substantially exceeds the proportional cost differential typically associated with certified seed procurement, generating favorable economic returns that should motivate farmer investment in quality planting materials. These findings support recommendations emphasizing seed system strengthening as a cost-effective pathway for improving wheat productivity in regions where farmer-saved seeds currently predominate.

Limitations

Several limitations should be considered when interpreting these findings. First, farmer-saved seed samples were collected from a specific geographic region and may not fully represent the diversity of seed-saving practices across broader areas. Second, the two-season duration of field trials, while providing valuable data, may not capture year-to-year variability under more extreme weather conditions. Third, economic analysis assumed prevailing market prices that fluctuate seasonally and regionally. Fourth, the research did not assess farmer perceptions, knowledge levels, and socioeconomic factors influencing seed source decisions. Future investigations should address these limitations through expanded geographic sampling, longer-term trials, and integration of socioeconomic assessments.

Conclusion

This comprehensive investigation provides quantitative evidence documenting substantial seed quality advantages of certified over farmer-saved wheat seeds and demonstrates that laboratory quality differences translate into economically meaningful field performance benefits. Certified seeds exhibited superior physical purity averaging 99.2% compared to 94.1% for farmer-saved materials, with corresponding reductions in inert matter, weed seed contamination, and other crop seed admixtures. Physiological quality parameters including germination percentage and vigor indices showed even greater disparities, with certified seeds maintaining values approximately 12-50% higher than farmer-saved counterparts depending on the specific parameter measured. Field performance assessments confirmed that laboratory quality measurements predict agronomic outcomes under actual production conditions. Crops established from certified seeds emerged an average of 2.3 days earlier, achieved plant stands approximately 14 percentage points higher, produced more tillers per plant, developed longer spikes with more grains, and ultimately delivered grain yields averaging 22.8% greater than crops grown from farmer-saved seeds. These yield advantages substantially exceeded the additional procurement costs associated with certified seed purchase, generating favorable economic returns that should motivate farmer investment in quality planting materials.

Correlation analysis identified vigor index as the laboratory parameter most strongly predictive of field yield performance, suggesting that vigor testing should receive emphasis in seed quality evaluation programs. The strong relationships between laboratory measurements and field outcomes support continued investment in seed testing infrastructure and certification systems as mechanisms for improving agricultural productivity. Extension efforts should communicate these findings to farmers using economic terms that demonstrate returns on seed quality

investments rather than relying solely on technical quality specifications that may lack intuitive meaning for practitioners.

The research outcomes have practical implications for multiple stakeholders involved in wheat seed systems. Farmers should be encouraged to invest in certified seeds particularly for initial plantings establishing new production cycles, reserving seed-saving for subsequent years only when proper handling and storage conditions can be maintained. Seed producers and certification agencies can utilize these data to justify quality premiums and communicate value propositions to farmer customers. Policymakers should consider these findings when designing seed sector development programs, subsidies, and quality assurance frameworks that promote utilization of high-quality planting materials as a pathway for sustainable agricultural intensification.

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