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Correlation Between Seed Longevity and Agronomic Traits in Wheat (*Triticum aestivum* L.)

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ABSTRACT: After rice, wheat is the second most significant cereal crop needed to provide human nutritional needs. Seed longevity is an important trait since it is associated with good germination and vigour. The performance and planting value of the seed lot in the following cropping season are determined by how long they remain viable and vigorous in storage. Since it is difficult and time-consuming to understand the genetic mechanism of longevity, an indirect approach that links agro-morphological characteristics with seed longevity could be investigated. In reference to this, the seeds of five wheat varieties of Himachal Pradesh, India were put under storage for 12 months in the seed testing laboratory and simultaneously analysed for 11 agro-morphological distinctive characteristics in the seed production farm. The correlation of germination after 12 months with 11 agro morphological parameters demonstrated a substantial and positive relationship between seed longevity and number of grains per spike, test weight, biological yield per plant, seed yield per plant, and productive tillers per plant. As a result, it is possible to create a wheat ideotype by selecting for more tillers per plant, more grains per spike, and test weight, all while increasing biological yield and seed production per plant. Based on association analysis, this study proposes an indirect selection criterion based on several easily scored agro-morphological factors that have a high relationship with seed longevity.

Keywords: Longevity, Correlation, Wheat, Viability, Cereals, Vigour

INTRODUCTION

Wheat is the first and most essential cereal crop for the substantial proportion of the world's population. It has been proclaimed as the "King of Cereals" due to its vast acerage, high productivity and the pivotal position it holds in the food grain trade. It is most essential staple food for almost 2 billion people (36%) of the world's population and is an important source of vegetal protein in human food, having a protein content of about 13% which is relatively high compared to other major cereals. It accounts for about 55% of all carbohydrates consumed globally and 20% of all food calories [1].

Seed is a vital plant product that will grow into an entire plant and should be alive until it is sown in the ensuing season. Thus, seed should have good storability; in other words, seed longevity and quality as measured by its vigour and vitality. These attributes play an important role in the establishment of seedlings as well as higher crop yields. A major cause of low vigour has been identified as seed ageing. The longevity of seeds in storage is influenced by four major factors, such as genetic constitution, quality of seed at the time of storage, moisture content of seed or ambient relative humidity and temperature of storage environment. Seed longevity is a quantitative trait and is strongly affected by the environment during seed formation, harvest, and storage [2]. Storage conditions like temperature in the storage and moisture contents of the seed are the most important factors affecting the losses. During storage the maintenance of seed quality is peremptory to the propagation of food plants as seed is the very first link in the food chain and considered as the ultimate symbol of food security. Uncovering the biochemical, genetic, molecular, and physiological factors that contribute to seed storability would aid in the improvement of traits in wheat.

Genetic and Molecular basis of seed longevity

Seed storability and viability are a complex characteristics to master. Seed longevity or storability becomes an attribute of attentiveness for wheat programmes, to alleviate the reduction of viability during storage because of its association with high germination and vigour. In recent years, many geneticists and seed technologists explored the genetics of seed longevity through breeding in wheat. Several researchers have looked into genetic and the molecular basis of seed storability in wheat [3] and rice [4] and have found quantitative trait loci that affect seed storability. It was reported that the accumulation of DNA lesions such as DNA strand breaks during storage has been linked to seed longevity reduction [5, 6] concluded that accelerated ageing effectively estimates seed longevity in wheat, rice, barley, pea and cabbage.

Structural and environmental basis of seed longevity

The impact of the environment on wheat grain production and flour quality during grain fill is significant. Temperature, water, and fertilizers all have diverse mechanisms that influence the rate and length of wheat grain development, protein accretion, and starch degradation. Several researchers have investigated the structural and environmental factors that influence the seed longevity. This section chronologically presents the findings of key published investigations.

In the earlier findings it was reported that the seed coat plays a major role in seed longevity, since it provides the principal defence against dangerous microbes and unfavourable climatic conditions [7]. It was found that germination, photosynthesis, tiller formation and inflorescence development are affected by the environment prior to anthesis, affecting grain numbers in wheat [8]. Furthermore [9] observed that wheat plants in various parts of the world including sections of United States, Australia, India and Mexico are subjected to periods of extreme heat, which drastically limits grain filling duration.

Biochemical basis of seed longevity

The physiology and biochemistry of seed degradation are still a mystery to us [10]. The bibliography compiled by [11] attests to the fact that most investigations during the years covered were concerned with establishing optimum conditions for producing, handling, storing and determining the longevity of seeds under various conditions, with very little research on mechanisms of deterioration. This section summarizes the findings of major published investigations in chronological order.

[12] investigated the protein alterations in wheat seeds that had been stored for 24 months under various conditions that cause various levels of degradation. [13] found that the activity of cytohormone oxidase and malic dehydrogenase was positively correlated with seed germinability.

[14] measured the soluble sugar contents and antioxidant enzyme activities in the embryo of wheat seeds throughout their storage under two conditions (45°C &100% RH and 30°C & 75% RH) to investigate whether grain deterioration during ageing was related to lipid peroxidation resulting in a decrease in the efficiency of the antioxidant defense system and changes in sugar metabolism. They suggested that ageing was associated with various mechanisms depending on the conditions of ageing, and that accelerated ageing at 45°C and 100% RH was not the only model to consider in order to understand the mechanisms involved in seed deterioration.

[15] evaluated transgenic strains that had their ^”-gliadins silenced with RNAi. Silencing raised the concentration of other gluten proteins, which had a minor impact on quality parameters, according to mixograph testing. When ^”-gliadins have no direct effect on mixing or bread-making properties, the compensatory affection of the other prolamins may result in stronger dough with improved overmixing dough.

[16] proposed a technique to define epitope toxicity in wheat proteins, specifically the prolamins, by combining database resources, computational methods, and proteomic diagnostics.

[17] reported that the impairment of cellular macromolecules is one of the biochemical changes related to seed ageing. PUFAs, in particular, are vulnerable to ROS, and their peroxidation is a primary cause of seed quality, vigour and viability loss when stored at room temperature.

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Various testing methods used to study longevity

Seed longevity or shelf life is difficult to anticipate or quantify on a practical time scale. Several researchers stated that studying seed longevity under traditional storage conditions would take years [19, 20]. Consequently, in order to evaluate seed longevity, methods like accelerated ageing or controlled deterioration could be used to speed up the loss of viability. Various seed viability tests have yielded intriguing results, which are chronologically tabulated in Table 1.

Table 2 shows that previous researchers primarily used conventional, accelerated ageing and controlled deterioration methods to investigate seed storability under artificial ageing for short and long-term storage in order to assess seed longevity of genotype as well as the role and implications of various factors in governing seed longevity. [24] determined the thermodynamic functions associated with seed deterioration during seed storage under accelerated conditions using wheat and soybean [27] investigated morphological and molecular changes in scutellum and aleuron sections of naturally and artificially aged wheat seeds using TUNEL assay and DAPI staining. These findings were significant for understanding the process of wheat seed deterioration and also used for searching for sensitive seed ageing signals for developing tools to monitor seed viability under storage [33] evaluated and compared the performance of wheat and maize seed in different hermetic storage packing with conventionally used interwoven bags in ambient conditions and found that seeds stored in polypropylene bags deteriorated quickly which resulted in loss of seed vigour.

Treatments employed and their impact on enhancing seed longevity

Scientists have proposed different treatments in order to improve the seed longevity in wheat. Seed priming, nanoparticle treatment, hydropriming, and seed dressing are some of the chemical treatments that have been used to improve the seed longevity and other seed quality attributes. This section summarizes the findings of major prominent investigations in chronological order.

[34] reported the extremely low content of alpha-amylase in both untreated and invigorated wheat seeds.

[35] found that during the early stages of germination and development of seedling growth were higher in the hydration and dehydration treatments, but these effects can be abolished at the final count.

[36] revealed that after a priming treatment, the seeds can be kept under modest water or temperature stress for several hours to days to achieve the necessary longevity.

According to [37], if storage conditions are good, non-aerated pre-soaking treatments for 6-8 hours may be recommended to increase field performance and yield of stored wheat seeds. Furthermore, if aeration facilities are available, pre-sowing aerated hydration treatments may be used to increase crop performance, particularly for longer soaking variations.

[38] conducted an experiment to determine the longevity of fungicide-treated seeds of wheat cultivar by using the viability equation and concluded that the longevity of treated seeds was greater than that of untreated seeds.

[39] reported that the pre-storage dry treatment of wheat seeds with aspirin (@ 50 mg/kg of seed, catharanthus leaf powder, trigonella seed powder, bleaching powder (@ 2 g/kg of seed) and red chilli powder (@ 1g/kg of seed) may improve the germiniability and field performance.

[40] investigated the effect of cold helium plasma treatment on seed germination, growth, and yield of wheat. They discovered that treating seeds with 80W cold plasma dramatically improved seed germination potential, germination rate and physiological level of wheat, leading to the increased yield.

[41] showed that moderate intensity of dielectric barrier discharge (DBD) plasma had active impacts on wheat seed germination and growth. DBD plasma could also activate several physiological reactions in wheat seed, resulting in the increase of soluble protein production.

[42] evaluated the potential of hydro and aspirin (ASP) priming techniques to improve the germination of soft wheat seeds under salinity stress. Seeds of two wheat genotypes were first primed and then germinated and then grown in saline and non-saline conditions (0 and 120 mM NaCl) for 8 days. The results showed that priming of seeds in the presence or absence of salinity stress enhances germination traits under the saline conditions. Aspirin (ASP)-primed seeds were highest in germination percentage as compared to hydroprimed seeds and non-primed seeds.

Seed longevity under storage

There is currently very little information available about the nature of seed longevity in wheat, which accounts

Table 1 Various seed viability testing methods used for assessing seed longevity and their key findings

Seed viability testing methods	Key findings	References
Accelerated ageing test	Seed viability can be monitored less frequently than once five years.Seed longevity of different genotypes differed dramatically after accelerated ageing.	[6]
Grains stored under controlled conditions (at 15% and 19% MC) at constant temperature	For 70 days, the germination percentage of 15% and 16% moisture content wheat seeds held at 25°C remained constant. The respiration rate of 17-19% moisture content wheat seeds increased, while the germination declined at 25°C temperature, with storability time. Germination dropped from 98 to 92-89% Visible mould occurred when the dry matter losses were about 1% in 17-19% MC.	[21]
Controlled deterioration test to evaluate wheat seed vigour	The best combination of CD test for wheat crop was 45°C and 18% moisture content for 72 hours, which indicated a high capacity.	[22]
Natural storage of seeds (for 0,4 and 8 months) and Accelerated Ageing Test (40°C,100% RH) for 7 days	After 8 months of ambient storage, seed germination exceeded minimum seed certification standards of 80%.	[23]
Seeds stored at 35°C and 45°C under high relative humidity	In this study the thermodynamic functions of seed were investigated.Wheat seeds could be more stable than soybean seeds at a given temperature with lower moisture concenterations.	[24]
Seeds stored at 20.3± 2.3°C and 50.5 ± 6.3% RH (under ambient conditions upto 26 years)	Longevity remains high for atleast the first two years following harvest, but drops to zero in 5-23 years, yielding an average P… • among all the species of 8.6 ± 3.6 years	[25]
Germination monitoring of seeds stored under standard gene bank conditions (For 25 years)	Seeds from gene bank accessions are dried to a moisture content of 3-7% and preserved under near vacuum in aluminium foil bags at – 20 °C for long periods of time. The longevity of sub-standard seed lots appeared to be uncorrelated with initial germination. For cultivated material, there was a definite decrease in ($Pthr_{25}$) with increased initial germination.	[26]
Natural ageing and accelerated ageing test	The germination rate of 12 wheat genotypes exposed to natural or accelerated ageing were evaluated and they ranged from 11 to 93%. Seed germination loss was found to be associated with reduction in scutellum nuclear content and with the scutellum nuclei length to width ratio. Lower germination Na seed samples were larger and less apparent, whereas the shape of the scutellum remained identical. Whereas, AA treated seeds resulted in the loss of scutellum, cell structure and collapse of cell layers.	[27]
Seeds stored under long term storage conditions with low MC (5 ± 2%) at -18°C	There are significant variances in seed viability loss between species and within species. Eleven crops (oats, barley, maize, bread wheat, durum wheat faba bean and chickpea) demonstrated a modest viability decline of less than 5% after 20-24 years of storage when compared to their initial viability. Another group of crops (sorghum, triticale, orchard grass, tall fescue, common vetch, green pea, lentil, cabbage and tomatoes) showed a 5-10% loss in seed viability.	[28]
Visible and Near Infrared hyper spectral Imaging technique	SNV and SG preprocessing are more appropriate than MSC pre-processing. The SVM and PLS –DA algorithms might both be used to model the viability of wheat seeds.	[29]
Ex-situ storage of wheat seeds and barley seeds at 4°C at -20°C for 23-33 years.	The mean germination rate of wheat and barley seed samples stored at -20°C was 94% and 90% respectively, revealing no loss of initial viability. Wheat seed samples stored at 4°C had a germination rate of 62% while barley seed samples had a germination rate of 75%.	[30]
Accelerated ageing test	During ten month period of storage, seed germination ceased, although fatty acid and MDA (malondi aldehyde) increased. The germination rate of the stored seeds reduced 90% to 10% in less than 10 months.	[31]
Effect of Accelerated ageing test on viability and longevity of wheat seeds	At the conclusion of 5days of accelerated ageing, fresh seeds of wheat variety (lok1) showed the highest pooled germination, seedling vigour index-I, seedling vigour index-II as well as observed the biochemical parameters. Whereas, progressive ageing showed negative effect on biochemical parameters of the 5 days aged seeds of wheat variety (GW-496). Wheat variety (GW-496) recorded lowest average pooled protein content (9.78%), carbohydrate content (60.36%). alpha-amylase assay (6.19micromoles/mg/min) and high electrical conductivity (28.60us/cm/g) due to fast deterioration.	[32]

for the majority of seeds preserved in the global gene banks. However, few researchers have thoroughly studied the different factors that directly or indirectly affect the viability and germination rate of seeds under storage conditions [43, 44, 45].

It is obvious from the studies on seed longevity in storage shown in the table above that the most essential seed quality parameters decline during storage, regardless of the container used or the prevailing weather conditions. The initial moisture percentage of the seed, the lipid content of the seed and the type of the containers used have all been shown to have a significant impact on the longevity of stored seeds.

Association studies related to seed longevity in wheat

Seed viability after dry storage is characterized as seed longevity, which is essential for seed banks and supplies to the farmers with credible crop seeds. Seed shelf life is a challenging yet vital seed attribute. Seed germination rate is typically inversely proportional to seed longevity. Seed longevity was evaluated as germination ability after several years of storage in natural conditions [46]. Various studies have been carried out to better understand the mechanisms that govern seed longevity; however, these investigations are time-consuming and inconvenient due to the extensive procedures. The most favourable tests for detection of seed longevity in wheat are accelerated ageing and controlled deterioration tests, which also require maintenance of accurate relative humidity and temperature during storage. In light of the foregoing, it would be advantageous to develop an indirect selection criterion based on some conveniently discernable agro-morphological or seed quality parameters that have a strong relationship with longevity. There is not a lot information out there presented now about the nature of the wheat seed longevity association with agronomic traits. However, there are a few studies published on the relationship between seed longevity and agronomical and seed quality parameters in wheat (Table 2).

The Table 2 shows the positive and negative relations of various seed parameters [62] found that the combination of sequential germination tests and predetermination of monitoring intervals would provide an integrated and economic system for monitoring the viability of accessions [58] revealed that the free radical oxidative attack is the major cause of disruption and deteriorative changes observed in aged seeds.

Table 2. Studies on the association of seed longevity with certain agro-morphological and seed quality parameters

Seed quality parameters	Nature of correlation with seed longevity	Reference
Moisture content	Negative	[47, 48, 24, 49, 50]
Temperature	Negative	[51, 52]
Germination	Negative	[53, 54]
Grain yield per plant	Positive	[55, 56]
Electrical Conductivity	Negative	[32, 57]
Lipid peroxidation	Negative	[58, 13, 59, 60]
Viability	Positive	[61, 62]
Seed ageing	Positive	[58]
Test weight	Negative	[63]
Seed dormancy	Negative	[64]
Seed coat permeability	Negative	[65]

Studies on genetic variability, heritability, and genetic advance in wheat

Several researches have been carried out in the past to determine the genetic characteristics of wheat agro-morphological attributes [66] had showed that a character exhibiting high heritability may not necessarily give high genetic advance. When heritability is examined in conjunction with genetic advancement, it can be determined with more accuracy. As a result, in the selection process, a character with high heritability as well as high genetic progress will be useful [67].

[68] investigated the genetic variability, heritability and genetic advancements in 27 wheat genotypes for important yield attributing traits and found high PCV and GCV values for all the traits. [69] evaluated seven Fƒ progenies and their 8 parental lines of spring wheat for genetic parameters, coefficient of variability, genetic variance, heritability percentage and genetic advances for 7 quantitative traits.

Earlier, high PCV and GCV values have been reported for grain yield per plant, number of tillers per plant and number of grains per spike [68, 69, 70, 71, 72, 73] reported that genetic variances were greater than environmental variances for all the traits except spike length. Minimum PCV and GCV were recorded for days to 90% maturity, although it was high for grain yield [74] reported moderate estimates of PCV and GCV for days to 50% flowering, days to maturity, plant height, peduncle length and number of productive tillers per plant [72] studied thirty wheat genotypes and reported moderate estimates of PCV and GCV for biological yield per plant and number of productive tillers per plant. High PCV and moderate GCV values were reported in certain agronomic traits i.e., spike length (PCV = 20.40%, GCV= 19.55%), no. of grains per spike (PCV = 23.65%, GCV= 19.42%), grain weight per spike (PCV= 21.60%, GCV= 15.54%) and grain yield per plant (PCV= 28.24%, GCV= 18.12%). [75, 76] in bread wheat and [77] in rice reported the narrow disparities between genotypic and phenotypic coefficients of variation. [78] observed the moderate PCV and GCV in the case of peduncle length followed by flag leaf area (cm^2). Works of [68, 78, 79, 80, 81, 82, 83] described the extent of heritability and genetic progress as per cent of mean, as well as their combinations, for wheat agro-morphological traits.

The summarized studies above have found a wide range of heritability and genetic advance values for numerous wheat agro-morphological traits, ranging from low to high. High heritability has been reported for days to heading, number of tillers per plant, thousand grain weight, grain yield per plant, harvest index, and biological yield. High heritability coupled with high genetic advance has been documented for number of grains per spike, days to heading, days to 50% flowering, test weight and grain yield per plant. Likewise, for many other traits, distinct combinations of high, medium and low advancement have been documented, resulting in various generalizations about the benefits expected by simple selection as well as other recommended techniques of selection for the individual traits.

Wheat crop endures significant losses during harvesting and storage, particularly stored seeds that may deteriorate due to natural phenomenon [84]. One of the issues that reduces seed viability and germination percentages is the length of storage time [85]. Apart from the genetic effect on seed storability, the successful storage period is also determined by the physical and chemical parameters, such as seed moisture content, seed coat structure, storage temperature and relative humidity. Seed quality and longevity may be influenced by the storage factor, as stored seed is susceptible to deterioration. Wheat seed viability decreases by 2.5% with each year of storage if the seeds are kept at the same temperature [86]. The increased activity of analytical enzymes such as amylase, phospholipases, proteases and phytase which affects the viability and vigour of seeds, leads to natural deterioration of seeds over a prolonged period of storage. Furthermore [87] had studied the impact of storage conditions on DNA and rRNA structure as well as enzyme activity, respiration and membrane permeability.

While breeding efforts continue, high yield and resilience to biotic and abiotic stresses are frequently prioritized. On the other hand, seed quality characteristics that are crucial for optimum productivity are frequently overlooked. In recent years, India, like the rest of the world, has seen an increase in demand for high-quality seeds. Seed longevity has recently garnered more attention from academics due to rising demand, resulting in better knowledge of the mechanisms governing it and considerable breakthroughs in its management.

A large number of wheat varieties have been developed in Himachal Pradesh during the previous 2-3 decades and their agronomic performance has been documented. However, little information is known about the seed quality characteristics of these cultivars, particularly, seed longevity, which is critical for good crop stands and productivity. Seed life-span is a prelude for the future generation of any plant species. During reproductive phase of seed development, the mother plant acquires this complex, quantitative seed quality attribute. One of the oldest and most difficult challenges in plant biology is determining which factors contribute to longevity [88]. Studies of seed longevity conducted under conventional or optimal storage conditions would take a long time to complete and studies conducted under accelerated ageing or controlled conditions of temperature and relative humidity would necessitate a high level of skill in maintaining appropriate conditions in order to obtain accurate results. As a result, it would be preferable if an indirect selection criterion could be found based on some conveniently accessible agro-morphological and seed quality parameters that have strong relationship with longevity. Keeping all these aspects in view, five varieties of wheat were stored under ambient conditions as well as planted in the field during *Rabi* 2020 in order to investigate them for their storability and agronomic traits with the objectives to assess seed longevity of wheat varieties of Himachal Pradesh and to establish association of seed longevity with important agronomic traits in wheat.

MATERIALS AND METHODS

The laboratory experiment was carried out at Seed Technology Laboratory whereas the field experiment was conducted at the Experimental Farm of the Department of Seed Science and Technology, CSK HP Krishi Vishvavidyalaya Palampur during the year 2020-21. In order to assess the seed longevity, 5 kg freshly harvested seeds of 5 released and/in release pipeline varieties of wheat of Himachal Pradesh namely, HPW 249, HPW 349, HPW 360, HPW 368 and HPW 373 were procured from the seed store of Department of Seed Science and Technology, CSK HP Krishi Vishvavidyalaya, Palampur. The seeds of aforementioned varieties were dried to the initial moisture content of 12 per cent and were stored in HDPE (High Density Polyethylene) interwoven bags using Completely Randomized Design (CRD) in four replications under ambient laboratory conditions. The stored seeds from each replication of each variety were examined bimonthly for quality traits viz., moisture content, test weight, germination percentage, rate of germination, field emergence (%), seedling length (cm), dry matter of 10 seedlings (g), electrical conductivity (ìS/cm/g), seed vigour index-I & II and seed longevity for one year duration w.e.f August 2020 to August 2021. The seed quality analysis and data were recorded by using following methodology for essential quality parameters in laboratory:

Germination (%): The germination was recorded at bimonthly intervals until it fell below Indian Minimum Seed Standards using between paper methods as per ISTA procedure [89] in four replications of 100 seeds each.

$$\text{Germination (\%)} = \frac{\text{Number of normal seedlings germinated}}{\text{Number of seeds kept for germination}} \times 100$$

The first count was taken on 4th day, and the final count was taken on the 8th day of the germination test.

Moisture content (%): The moisture content was measured using a non-destructive moisture meter (Model: PM-600, Kett, Japan). A homogenous sample weighing 170 g was randomly taken from the bags of each replication of each variety, as per manufacturer's recommendation and the moisture content in per cent was recorded by using the moisture meter.

Test weight (g): To detect the test weight(g) a homogenous representative sample was drawn from the four replications of each variety and 1000 seeds were counted using seed counter and their weight was recorded in grams. For the detection of rate of germination (%) 100 seeds were randomly selected from each of the four replications and germinated in petri plates using the blotter paper method. Upto the final count, a daily germination count was kept. The rate of germination was calculated as per the procedure described by [90].

$$\text{Rate of germination} = n_1/d_1 + n_2/d_2 + n_3/d_3 + \ldots\ldots\ldots\ldots$$

where,

n = number of germinated seeds

d = number of days

The variety with the highest value had the fastest germination and was considered to be higher in vigour.

Field emergence (%): The field emergence of stored wheat seeds was calculated by sowing the seeds of every variety in four replications of 100 seeds each. The seeds were planted at a depth of 3 to 5 cm in the soil. The number of seedlings emerging above the soil surface on 8th day of planting was taken into account, and the field emergence was computed as:

$$\text{Field emergence (\%)} = \frac{\text{The number of seedlings emerged on } 8^{th} \text{ day}}{\text{Total number of seeds sown}} \times 100$$

Seedling length (cm): At the end of the germination period (8th day), ten normal seedlings from each replication of each variety were chosen at random. Each seedling was measured from the primary leaf tip to the root tip. The average length was determined and represented in centimeters.

Dry matter of 10 seedling (g): The ten seedlings used to assess seedling length were enveloped with butter paper and dried in hot air oven at 80°C for 17 hours. The dry weight of the seedling was recorded after 17 hours and the dry weight of the seedling was calculated in grams.

Electrical conductivity (µS/cm/g): For the computation of EC, 5g seeds from each replication of each genotype of four replications were weighed. Then these seeds were soaked in 50 ml of distilled water in a beaker for 17 hours at 25 ± 1°C. After 17 hours of soaking, the solution was decanted, and the EC of the solution was measured using a digital conductivity meter and expressed in µS/cm/g.

Seed Vigour Index I&II: The seed vigour index was computed using Abdul-Baki and Andreson's approach (1973). The following formula was used to determine the seed vigour index I&II:

Seed Vigour Index-I = Final count% × Mean seedling length (cm)

Seed Vigour Index-II = Final count% × Mean seedling dry weight (g)

Seed longevity (IMSCS): Seed longevity was assumed to be the duration in months up to which the seed

Table 3. Seed longevity categorization

Months after which percent germination falls below IMSCS	Seed longevity categorization
< 8 months of storage	Short seed longevity
8-10 months of storage	Medium seed longevity
> 10 months of storage	Long seed longevity

maintains its germination percentage above the Indian Minimum Seed Certification Standard (IMSCS). In the case of wheat, the IMSCS is 85%. Based on the range of seed longevity in the material kept under study, the genotypes were grouped into three categories as per the details given in Table 3.

For the field experiment, seed lots of all varieties were assessed for agronomic traits by growing all five varieties in the experimental farm following three replications in a randomized block design (RBD). The size of the plot was 3 m × 1.10 m. The experimental material was planted on 13th November, 2020. Wheat seeds were planted in rows by the line sowing method and were thoroughly covered with soil. The depth of the seedling in the field was kept at 2 to 5 cm. The row-to-row spacing was kept at 22cm. Seed rate of 100 kg per hectare and other cultural practices were followed as per the recommended package of practices of the university. The parameters viz., days to 50% heading, plant height (cm), productive tillers per plant, peduncle length (cm), number of grains per spike, days to physiological maturity, spike length (cm), biological yield per plant (g) and seed yield per plant (g) were recorded on 10 randomly selected plants in each plot during crop growth and after the crop was harvested. Standard statistical procedures were used for analysis of variance, genotypic and phenotypic coefficient of variation, heritability and genetic advance. The association analysis was worked out using MVM software. Some essential field parameters were detected by using the following strategy:

Days to 50% heading: Heading time was recorded as the number of days from date of sowing to the apperance of complete spike having left the flag leaf of 50% of plants per genotype.

Plant height (cm): At physiological maturity, height of ten randomly selected plants from the base above the soil surface upto the tip of the main ear was recorded and the mean height was computed.

Productive tillers per plant: Productive tillers were additional stems (bearing spikes) that develop off the main shoot of the plant. Total number of tillers per plant (tillers bearing spike) of ten randomly selected plants from each variety of tree replications was counted at maturity.

Peduncle Length (cm) : Peduncle length is the length of the religion between the spike base and the flag leaf. Ten plants were randomly selected from each plot of each variety, and peduncle length was measured by using a cm scale.

Number of grains per spike : Ten spikes were randomly selected from each plot, threshed separately, and the number of grains of each spike was counted and averaged.

Days to physiological maturity: Days to physiological maturity in each sub plot was measured by counting the days from sowing date to the date when 70 to 80% plants become physiological mature. The observation was recorded separately for each replication of every variety.

Spike Length (cm): Ten spikes were randomly selected from ten selected plants, and the length of the spike from tip to the base of the spike/ear was measured in cm.

Biological Yield per Plant (g): The ten plants from each plot were harvested, and the ten selected plants were weighed and the weight was recorded as biological yield per plant in g.

Seed yield per plant (g): To record the seed yield per plant , ten selected plants were threshed and weighed. The mean was worked out and recorded in grams.

Harvest Index (%): The harvest index was worked out as the ratio of seed yield per plot to biological yield per plot and was expressed in per cent. The standard formula used for calculating harvest index is:

$$\text{Harvest Index (\%)} = \frac{\text{Seed yield per plot}}{\text{Biological yield per plot}} \times 100$$

Test weight (g) : A homogenous representative sample was drawn from the harvested seeds of each plot and 1000 seeds were counted from the sample and then weight was obtained in grams.

RESULTS AND DISCUSSION

The material kept in storage for 12 months revealed that seed quality attributes such as moisture content (%) of seed and test weight (g) varied throughout the storage time and fluctuated with temperature and ambient relative humidity of the storage environment. However, germination per cent- first count and final count (Figure

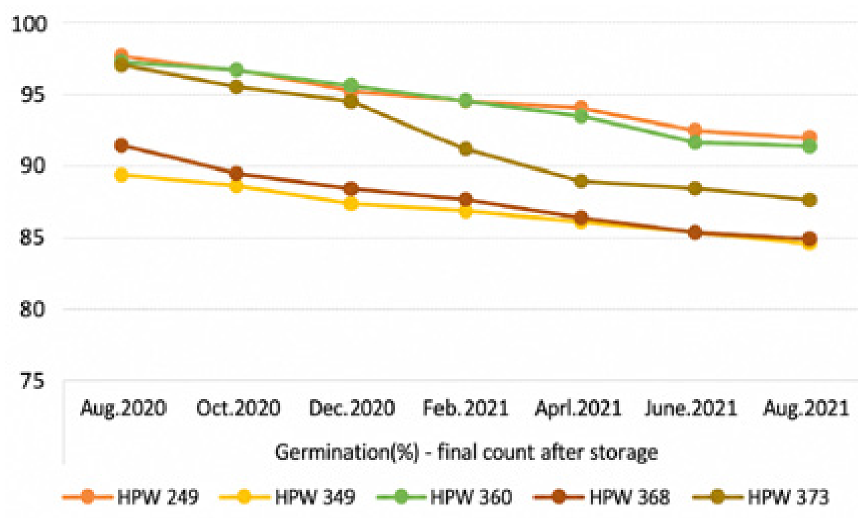

Figure 1. Tentative categorization of five wheat varieties of Himachal Pradesh based on inferred seed longevity and comparitive germination

1), seedling length, seedling dry weight, SVI-I, SVI-II and field emergence declined with the progression in storage whereas the electrical conductivity progressively increased in all five varieties of wheat. Seed moisture content and storage temperature perhaps , play the most dominant role in maintaining good seed viability during storage [91, 92] reported that there was a relation between temperature of storage moisture inside seeds and their longevity.

In the present study, seed longevity was inferred and recorded as the time period up to which the seeds of the variety under storage conditions maintained its per cent germination above the Indian Minimum Seed Standards (85%). Seed viability after dry storage is characterized as seed longevity, which is essential for seed banks and supplies to the farmers with credible crop seeds. Seed shelf life is a challenging yet vital seed attribute. Seed germination rate is typically inversely proportional to seed longevity. Seed longevity was evaluated as germination ability after several years of storage in natural conditions. Seed longevity of five varieties of wheat of Himachal Pradesh inferred from the germination- final count data revealed the maintenance of germination- final count of more than 85% in variety HPW 349 up to 10 months and in other four varieties beyond 12 months of storage. From the inferred seed longevity and its tentative categorization into short, medium and long seed longevity summarized in Table 4, HPW 349 can be categorized as having medium seed longevity whereas remaining four varieties, namely HPW 249, HPW 360, HPW 368 and HPW 373 had long seed longevity. The seed longevity duration clearly indicated that HPW 349 could be stored safely only until the next growing season and cannot be carried forward. On the other hand HPW 249, HPW 360, HPW 368 and HPW 373 varieties maintained the germination percentage above IMSCS upto 10 months of storage. However, the highest storage life was recorded for HPW 249 as its germination percentage did not fall below the IMSCS even after 12 months of storage. Seed longevity in the present study is comparatively higher as compared to the findings of the study conducted by [93], who reported maintenance of seed longevity up to 6 months of storage. Various studies have been carried out to better understand the mechanisms that govern seed longevity; however, these investigations are time-consuming and inconvenient due to the extensive procedures. The most favorable tests for detection of seed longevity in wheat are accelerated ageing and controlled deterioration tests, which also require maintenance of accurate relative humidity and temperature during storage.

Table 4. Tentative categorization of five wheat varieties of Himachal Pradesh based on inferred seed longevity and Comparitive germination%- final count of five varieties of wheat over 12 months of storage

Category	Months after which per cent germination falls below IMSCS	Variety(ies)
Short seed longevity	<8 months	-
Medium seed longevity	8-10 months	HPW 349
Long seed longevity	>10 months	HPW 249, HPW 360, HPW 368, HPW 373

The analysis of variance revealed that the mean sum of squares due to genotypes were significant for all the agro-morphological traits except spike length, which was found non-significant under study as shown in Table 2. High PCV and GCV values (>20%) were observed for peduncle length, whereas traits like days to 50% heading, number of grains per spike, biological yield per plant and seed yield per plant exhibited moderate PCV and GCV values (10 to 20%). In general, the PCV values were greater than the GCV values, which meant that the genotypes were influenced by the environment to an extent. However, high heritability (75-100%) for days to 50% heading, plant height, peduncle length, days to physiological maturity, harvest index and number of grains per spike indicated that the environmental influence was very low and variation observed was mainly under genetic control. Several researches have been carried out in past to determine the genetic characteristics of wheat agro-morphological attributes [94] had showed that a character exhibiting high heritability may not necessarily give high genetic advance. When heritability is examined in conjunction with genetic advancement, it can be determined with more accuracy. As a result, in the selection process, a character with high heritability as well as high genetic progress will be useful [67]. Earlier, high PCV and GCV values have been reported for grain yield per plant, number of tillers per plant and number of grains per spike [68, 69, 70, 71, 72].

Field performance of all the genotypes varied significantly for all the 11 agro-morphological parameters under study, as shown in Tables 5 & 6. HPW 249, HPW 373, HPW 349 and HPW 368 were the earliest to reach 50% heading (102-104 days), whereas HPW 360 took the maximum number of days to reach 50% heading (139 days). HPW 249 recorded the highest values for number of tillers per plant (4.46), plant height (82.90 cm), peduncle length (cm), number of grains per spike (59), test weight (47.45), biological yield per plant (21.78 g) and seed yield per plant (12.07 g). HPW 368 recorded the shortest plant height (72.12 cm) and the lowest test weight (43.01 g).

Table 5. Mean performance of five varieties of wheat for 11 agro-morphological traits

Variety	Days to 50% heading	Plant height (cm)	Productive tillers per plant	Peduncle length (cm)	Spike length (cm)	Number of grains per spike	Days to physiological maturity	Biological yield/ plant(g)	Seed yield/ plant(g)	Harvest index (%)	Test weight (g)
HPW 249	102.00	82.90	4.46	19.40	4.50	59.00	164.00	21.78	12.07	55.47	47.45
HPW 349	104.00	73.22	4.16	16.50	4.20	49.00	165.00	16.05	9.97	62.05	44.83
HPW 360	138.00	81.21	4.30	10.80	4.20	51.00	190.00	18.79	10.50	55.87	47.30
HPW 368	104.00	72.12	4.10	16.40	4.10	41.30	165.00	15.92	8.01	50.34	43.01
HPW 373	102.00	82.48	4.10	17.40	4.30	52.60	165.00	18.55	9.77	52.65	45.36
Mean	111.00	78.38	4.22	16.12	4.26	50.58	169.79	18.21	10.06	55.27	45.59
SE(m)±	0.22	1.16	0.04	1.20	0.10	1.85	0.40	0.21	0.56	0.94	0.76
CD (5%)	0.74	3.86	0.15	3.82	NS	6.12	1.32	0.69	1.87	3.11	2.54

Table 6. Estimates of mean, range and other genetic parameters for 11 agro-morphological traits in wheat

Trait	Mean ± SE	Coefficient of variation (CV %)	Range	Phenotypic Coefficient of Variation (PCV %)	Genotypic Coefficient of Variation (GCV %)	Heritability in broad sense (%)	Genetic advance as % of mean
Days to 50% heading	110.53 ± 0.22	0.29	102.3-138.6	14.26	14.26	99.96	29.36
Plant height(cm)	78.38 ± 1.16	2.58	72.12-82.90	7.05	6.56	86.62	12.57
Productive tillers per plant	4.22 ± 0.04	2.16	4.10-4.46	3.75	3.07	66.88	5.17
Peduncle length (cm)	16.12 ± 1.20	10.77	10.80-19.40	21.71	18.85	75.38	33.71
Spike length (cm)	4.26 ± 0.10	5.85	4.1-4.5	6.00	1.35	5.06	0.63
Number of grains per spike	50.58 ± 1.85	4.94	52.6-59.0	14.71	13.86	88.73	26.89
Days to physiological maturity	169.78±0.40	0.52	164.3-190	6.71	6.69	99.41	13.75
Biological yield per plant (g)	18.21 ± 0.21	2.00	15.92-21.78	13.30	13.15	97.73	26.78
Seed yield per plant (g)	10.06 ± 0.56	9.72	8.01-12.07	16.52	13.35	65.35	22.24
Harvest index (%)	55.27 ± 0.94	2.95	50.34-62.05	8.32	7.78	87.41	14.98
Test weight (g)	45.59 ± 0.76	2.34	45.36-47.45	3.89	3.11	63.84	5.12

Table 7. Estimation of phenotypic (P) and genotypic (G) correlation coefficients between agronomic traits and germination after 12 months of seed storage in five varieties of wheat

Trait	Days to 50% heading	Plant height	Productive tillers per plant	Peduncle length	Spike length	Number of grains per spike	Days to physiological maturity	Biological yield/ plant	Seed yield/ plant	Harvest index	Test weight
Plant height	P 0.281										
	G 0.302										
Productive tillers per plant	P 0.061	0.138									
	G 0.077	0.337									
Peduncle length	P 0.225	0.598*	0.151								
	G 0.252	0.708**	0.311								
Spike length	P -0.247	-0.453	0.085	-0.030							
	G-1.131	-2.227	0.264	-0.648*							
Number of grains per spike	P 0.109	0.017	0.756**	0.271	0.157						
	G 0.118	0.067	0.991**	0.466	1.370						
Days to physiological maturity	P 0.994**	0.275	0.116	0.213	-0.260	0.016					
	G 0.998**	0.302	0.155	0.247	-1.026	0.178					
Biological yield/plant	P 0.017	0.334	0.868**	0.253	-0.050	0.777**	0.086				
	G 0.017	0.373	1.067	0.249	0.115	0.853**	0.082				
Seed yield/plant	P -0.151	-0.081	0.680**	0.046	-0.040	0.885**	-0.070	0.772**			
	G-0.181	-0.046	1.096	0.267	2.258	0.981**	-0.123	0.939**			
Harvest index	P -0.325	-0.697**	0.053	-0.109	0.439	0.384	-0.301	-0.064	0.420		
	G-0.341	-0.825**	0.042	-0.075	3.048	0.0409	-0.335	-0.081	0.428		
Test weight	P 0.018	-0.487	0.464	-0.407	0.312	0.419	0.070	0.442	0.437	0.231	
	G 0.018	-0.520	0.681**	-0.685**	1.023	0.590*	0.083	0.573*	0.794**	0.412	
Seed germination (after12 months of storage)	P -0.095	0.080	0.646*	-0.049	0.181	0.569*	-0.031	0.837**	0.612*	-0.054	0.677**
	G-0.112	0.043	1.067	-0.270	-0.034	0.738**	-0.037	0.944**	0.962**	0.008	0.855**

*Significant at 5% level; **Significant at 1% level

HPW 349 exhibited the lowest seed yield per plant (8.01 g) and harvest index (50.34%).

The correlation coefficients among per cent germination (after 12 months of seed storage) and agronomic traits were worked out at both genotypic and phenotypic levels as shown in Table 7. The results showed that genotypic correlations in general were higher in magnitude than phenotypic ones, indicating the role of environment in the expression of genetic association of the traits. Per cent germination (after 12 months of storage) taken as indicator of seed longevity was found to be positively associated with productive tillers per plant, number of grains per spike, test weight, biological yield per plant, and seed yield per plant. None of the traits was found significantly negatively correlated with seed longevity/ germination after 12 months of seed storage. From the correlation analysis it was found that, genotype exhibiting more number of tillers per plant, more number of grains per spike, biological yield per plant, seed yield per plant and test weight would be more productive and is likely to have higher per cent germination for a longer period of time and hence seed longevity under seed storage. These associations are in agreement with earlier reports of [95, 96, 97, 98, 99, 100, 101]. There is scanty information in literature on the nature of association between wheat seed longevity and agronomic traits. However, [102] showed that wheat grain yield was positively correlated with 1000-grain weight. [103] reported a positive correlation of grain yield with number of grains per spike, plant height and 1000 grain weight. [104, 105] also conducted such studies and concluded that yield components like tillers per plant, grains per spike and 1000 seed weight are main contributors to grain yield in wheat. [100] reported that grain yield per plant showed a positive and significant correlation with flag leaf area, tillers per plant, spike length, grains per spike, grain weight per spike and 1000 seed weight. [101] reported that tiller number, grain weight per spike, number of grains per spike exhibited positive and strong association and maximum positive effect on grain yield. The results of the present study are also in agreement with the findings of [106] and [107] who observed significant and positive correlation of seed yield with several agronomic traits in wheat.

CONCLUSIONS

Seed longevity has a direct role in determining the plantability of the seed lot. Understanding correlation between the morphological traits and seed longevity could strengthen the selection programme of the modern breeders. The research indicated the correlation of seed longevity with some easily accessible agro-morphological traits of wheat. An ideal wheat genotype should have more number of productive tillers per plant, more number of grains per spike, higher biological and seed yield per plant, and test weight in order to have more productivity and seed longevity. The information gleaned in this study on the magnitudes and direction of association between seed longevity and the component traits can be employed in crop improvement programmes to achieve the improvement in desired direction with respect to seed longevity.

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