Effect of storage conditions on seeds vigor, growth, and grain yield in bread wheat Varieties

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ABSTRACT

Two experiments were conducted, one laboratory experiment and the other a field experiment. The first experiment was conducted in 2025 in Babylon Governorate at two locations: the first at the Seed Testing and Certification Directorate – Babil Branch, and the second at the Mesopotamia Company – Babil. The second field experiment was conducted at the experimental field of the Department of Field Crops, College of Agriculture, Al-Qasim Green University, located south of Hillah City, Babylon Governorate. The above experiments aimed to investigate the effect of storage conditions and cultivars on seed vigor, growth, and grain yield of bread wheat (*Triticum aestivum* L.).

The laboratory experiment was conducted as a factorial experiment using a Completely Randomized Design (CRD), whereas the field experiment was conducted as a factorial experiment using a Randomized Complete Block Design (RCBD).

The experiments included two factors. The first factor comprised three storage conditions: refrigerated storage, incubator storage, and storage in wheat seed warehouses. The second factor comprised three wheat cultivars: IPA 99, Buhuth 22, and Sham 6.

The results demonstrated the superiority of refrigerated storage across most of the studied traits, recording the highest means for germination percentage, seedling dry weight, flag leaf area, number of spikes, and number of grains per spike, compared with incubator and warehouse storage. The effect of cultivars also revealed the superiority of the IPA 99 cultivar for most of the studied traits, although the cultivars differed in their responses to storage conditions. The interaction between storage conditions and cultivars had a significant effect on several traits, with IPA 99 under refrigerated storage exhibiting superior performance for some traits, whereas other combinations recorded the lowest values under incubator storage. These findings highlight the importance of the interaction between cultivar and storage conditions in maintaining seed viability and its subsequent effects on growth traits and yield components.

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Introduction -1

Wheat (*Triticum aestivum* L.) is considered the world's most important strategic crop, ranking first in terms of cultivated area and production. In Iraq, the area cultivated with this crop was estimated at 8,117 dunums during the winter season of 2024, with an average yield of 640 kg dunum^{-1}, based on the total cultivated area.

-The development of technology based conventional agriculture represents a profound transformation in agricultural practices, enhancing efficiency, sustainability, and productivity. Sensors are an integral rt of smart agriculture systems, as pa they contribute to collecting the data making in -required for sound decision agricultural practices [1,2]. A smart agriculture system equipped with the Internet of Things (IoT), a camera with etwork, Fi n-a microcontroller, a Wi and smart devices for remote control connected to the Internet represents one of the advanced practices that support production].and reduce waste [3

This development has also included warehouse management using smart devices that contribute to itoring and assessing storage mon efficiency in order to reduce seed losses resulting from environmental conditions and storage pests. Among the most important smart applications are temperature and humidity sensors, which monitor storage conditions and mmediate alerts when changes send i occur that may affect seed quality .[4,5]

Wheat storage in silos, warehouses, or designated rooms is one of the essential stages in the global grain handling chain. Grains may be stored for varying periods, ranging].to years [6 from weeks

Storage reduces the contribution of seed vigor to yield in two ways. First, it affects the percentage and rate of emergence, resulting in reduced field stand density per unit area and uniform seedling growth and -non ts in the emergence. Second, it resul establishment of weak plants in the field, thereby affecting field establishment and the production of vigorous seedlings [7,8,9]. Storage also affects grains intended for human consumption, causing losses in nutritional value, particularly when grains are stored for long periods under high temperature and humidity. Such conditions lead to reductions in vitamin content, protein deterioration due to oxidation, and losses of essential fatty acids as a result of rancidity [10]. Poor s also increase storage condition microbial contamination, insect infestation, loss of germination capacity, and].deterioration of nutritional value [11

Numerous studies have shown that seed viability and activity vary among different genetic backgrounds. The ability of eds to adapt to and withstand se different environmental conditions, particularly temperature and humidity, is influenced by their genetic makeup [12]. This explains why some cultivars can tolerate or resist certain environmental tivars conditions, whereas other cul are severely affected by the same conditions [13]. The precise explanation for these differences among genetic backgrounds under changing storage conditions may not always be clear; they may be related

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to the seed's nutrient reserves or tent, which in turn hormonal con influence its response to tem].perature and humidity [14

Wheat cultivars are characterized by different physical and chemical properties that influence their ability to resist biotic damage and other environmental high protein ,factors. For example content and grain hardness have been shown to be associated with a lower level of damage].caused by some storage pests [15

Given the limited number of studies investigating the use of remote monitoring and control systems for regulating temperature and relative humidity in seed storage facilities, and their effects on seed viability and the content of essential biochemical compounds in local wheat cultivars, The study aimed to investigate the effects of different storage conditions on seed viability, seed vigor, and field emergence of three local wheat cultivars, as well as to evaluate growth traits, grain yield, and its components in these cultivars under different storage conditions. Furthermore, the study aimed to assess seed storage methods using smart storage technologies.

Materials and Methods -2

A set of smart devices was used to monitor wheat grain storage cluding temperature conditions, in and humidity sensors, motion sensors (PIR), and smart surveillance cameras. Suitable models were selected based on cost, accuracy, and.ease of connection to smartphones

The laboratory experiment was conducted during the summer f 2025 at two locations: the season o Seed Testing and Certification Babil Branch and the –Directorate General Mesopotamia Company, with the aim of storing the seeds under the.experimental conditions

The factorial experiments were arranged according to a Completely Randomized Design (CRD), and the treatments included in the experiment are presented in Table .(1)

Table 1. Factors included in the study

Storage conditions	Storage location	Treatment code	Treatment
(conditions Factor 1 (Storage			
Temperature: 10°C %30–Humidity: 20	Refrigerator	S1	Refrigerated storage
Temperature: 40 ± C°5 %50–Humidity: 40	Seed Testing and Certification Babil –Directorate Branch (incubator storage)	S2	Controlled storage
–Temperature: 25 C°40 %40–Humidity: 20 Uncontrolled	Mesopotamia Company for Babil –Grains Branch	S3	Actual storage

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conditions	warehouse) (storage		
Genetic origin	Grain source	Treatment code	Treatment
(Factor 2 (Cultivars			
from Originated national breeding and genetic improvement programs	Mesopotamia Company for Babil –Grains Branch	V1	99IPA
A genetic line developed within Iraqi agricultural research programs	Agricultural Research Abu –Directorate Ghraib	V2	Bohuth 22 cultivar
Improved genetic line	Agricultural Research Abu –Directorate ibGhra	V3	Sham 6 cultivar

Laboratory Tests

Standard Laboratory -1

(%) Germination Test

A total of 300 seeds were randomly selected and arranged in rows, then wrapped in moistened blotter paper 100 towel test, with-using the rolled seeds in each roll and three replications. The rolls were placed on shelves inside the germinator at the Seed Testing and Certification Babil Branch at 20°C. –Directorate After 7 days from the beginning of germination, the number of was counted germinated seedlings and converted to a percentage g to the followingaccordin].equation [16

Normal seedlings (%) = (Number of normal seedlings / Total number of .seeds) × 100

2- Seedling Dry Weight (mg)

The seedlings whose radicle and coleoptile lengths had been measured were placed separately in perforated paper bags and dried in an electric oven at 65°C for 24 hours. They were then weighed using a sensitive electronic balance. The mean dry radicle and coleoptile weight of the was determined, and the total seedling dry weight was obtained by summing the two].weights [17

Field Experiment

The field experiment was conducted during the winter season of 2025–2026 in the field belonging to the Field Crops Department,

Qasim Green -College of Agriculture | Al University, in the center of Babil Governorate, located at latitude 32°40′ N and .longitude 44°39′ E

The experimental field was ploughed using a moldboard plough in perpendicular directions, followed by

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harrowing, land leveling, and field division according to the RCBD, with the factorial arrangement and three replications. The physical and chemical properties of the soil were measured as shown).in Table (2

Table 2. Measurement of the Physical and Chemical Properties of the Soil

Value	Property
1.18	[1])of irrigation water Electrical conductivity (EC) (dS m
3.6	[1])of field soil Electrical conductivity (EC) (dS m
7.96	irrigation water Soil pH of
7.3	Soil pH of field soil
21.1	[1]) Available nitrogen (mg kg
24.2	[1]) Available phosphorus (mg kg
381	[1]) Available potassium (mg kg
1.36	% Organic matter
224	[1]) Sand (g kg
345	[1]) Clay (g kg
428	[1]) Silt (g kg
clay loam Silty	Soil texture

Field Experiment Traits

(²Flag Leaf Area (cm -1

Flag leaf area was measured at full flowering using the mean of 10 flag leaves from the main stems, selected randomly from each experimental following unit, according to the .[equation [18

Leaf length = (²Flag leaf area (cm cm) × Leaf width at the midpoint) cm) × 0.95)××

[2]) Number of Spikes (spikes m 2-

The number of spikes within the meter area of -square-harvested one rimental unit was counted each expe .manually

-3)Number of Grains per Spike (grains [1] spike

The number of grains was determined for the ten spikes previously selected at random. The spikes were manually threshed, and the mean calculated number of grains per spike was.

Results and Discussion3-

Standard Laboratory Germination -1 (%) Test

The results of the analysis of variance and Table (3) showed a significant effect of storage conditions on germination percentage. Refrigerated storage was significantly superior, recording the highest mean germination percentage of 89.42%, compared ncubator storage, which with i recorded the lowest mean of The cultivars and their .%72.18 interaction did not show significant .differences for this trait

This may be explained by the fact that prolonged storage gradually iability as a result of reduces seed v changes occurring within the seed during storage. Researchers have indicated that storage affects cell

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membranes, nucleic acids, proteins, and enzymes, ultimately reducing the embryo's ability to germinate. ble Lower temperature and sta storage conditions help maintain seed viability and limit deterioration processes, whereas fluctuations in temperature and environmental conditions accelerate viability loss and reduce germination capacity. This agrees with the]findings of 19,20,21]

Table 3. Effect of Storage Conditions, Cultivars, and Their Interaction on Germination Percentage

Mean effect of storage conditions	Cultivars			Storage conditions
	Sham 6	Buhuth 22	IPA99	
89.42	88.67	88.59	91.00	**Refrigerated storage**
72.18	72.20	70.67	73.68	**Incubator storage**
81.57	81.33	78.70	84.67	**Warehouse storage**
2.303	NS			**L.S.D. 0.05**
	80.73	79.32	83.11	**Mean effect of cultivars**
	2.303			**L.S.D. 0.05**

)Seedling Dry Weight (mg2-

The results in Table (4) showed a effect of storage significant conditions and cultivars on seedling dry weight. Refrigerated storage was significantly superior, recording the highest mean dry weight of mg, compared with incubator 0.045 storage, which recorded the lowest ars, mean of 0.034 mg. Among cultiv Abba 99 was superior, recording mg, whereas Sham 6 recorded 0.040 the lowest seedling dry weight of mg. The interaction did not 0.039 show significant differences for this .trait

This reduction may be attributed to the fact that seed deterioration during storage decreases the ability of seeds to germinate, grow, and produce vigorous seedlings, thereby reducing the amount of dry matter accumulated in the seedling. Seeds with high viability are more capable of utilizing their stored reserves during germination and developing a more vigorous root and shoot system. In contrast, seed deterioration weakens seedling growth and reduces its dry weight. This is because prolonged storage depletes the nutrients stored in the seeds and reduces their viability, consequently decreasing their ability to supply the materials required for seedling growth. Therefore, a gradual decrease in dry weight was observed with increasing storage duration. This result agrees with [22,19,8].

Table 4. Effect of Storage Conditions, Cultivars, and tnteraction on Seedling Dry WeighTheir I

Mean effect of storage conditions	Cultivars			Storage conditions
	Sham 6	Bohuth 22	IPA 99	
0.045	0.043	0.046	0.046	**Refrigerated storage**
0.034	0.039	0.030	0.033	**storage Incubator**
0.038	0.036	0.039	0.041	**Warehouse storage**
0.000990	0.000990			**L.S.D. 0.05**
	0.039	0.038	0.040	**Mean effect of cultivars**
	0.001715			**L.S.D. 0.05**

3- Flag Leaf Area (cm²)

The results in Table (5) of showed a significant effect storage conditions and cultivars on flag leaf area. Refrigerated storage was significantly superior, recording the highest compared ,²mean of 44.19 cm with incubator storage, which recorded the lowest mean of Among cultivars, .²cm 36.04 erior, recording Abba 99 was sup whereas Sham 6 ,²cm 42.02 recorded the lowest flag leaf area For the interaction, .²of 38.11 cm the combination of refrigerated storage and Abba 99 recorded the ,²highest leaf area of 45.97 cm compared with the combination rage and Sham 6, of incubator sto which recorded the lowest value .²of 31.40 cm

The significant differences among wheat cultivars in flag leaf area may be attributed primarily to genetic variation among cultivars, which influences leaf growth, expansion, and the efficiency of assimilate production. The superiority of IPA 99 in flag leaf area compared with the other cultivars may indicate its greater genetic capacity for leaf expansion and its ability to maintain vegetative growth under the prevailing environmental conditions. In contrast, the lower flag leaf area recorded by Sham 6 may be associated with differences in its genetic characteristics and growth pattern. These differences among cultivars reflect the variation in their genetic potential and their ability to utilize available environmental resources, which ultimately affects flag leaf development. This result agrees with(12)

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Table 5. Effect of Storage Conditions, Cultivars, and Their Interaction on Flag Leaf Area (cm^2)

effect of storage conditions Mean	Cultivars			Storage conditions
	Sham 6	Bohuth 22	Abba 99	
44.19	43.31	43.30	45.97	**Refrigerated storage**
36.04	31.40	35.83	40.90	**Incubator storage**
39.36	39.63	39.23	39.20	**Warehouse storage**
2.175	3.766			**L.S.D. 0.05**
	38.11	39.46	42.02	**Mean effect of cultivars**
	2.175			**L.S.D. 0.05**

^{2})□Number of Spikes (spikes m4-

The results in Table (6) showed a significant ect of storage conditions and cultivars on the ^{2}) .□number of spikes (spikes m storage was Refrigerated significantly superior, recording the ,²□highest mean of 403.11 spikes m compared with incubator storage, which recorded the lowest mean of Among .²□spikes m 346.13 cultivars, Abba 99 was superior, ,²□recording 382.21 spikes m uth 22, which compared with Boh 62.42recorded the lowest mean of 3 For the interaction, .²□spikes m Sham 6 under refrigerated storage recorded the highest mean number ,²□of spikes, 429.02 spikes m compared with the interaction of Sham 6 under incubator storage, ed the lowest mean for which record this trait, 308.01^2.□spikes m

This may be attributed to the fact that low temperatures help maintain seed viability and vigor and reduce the rate of physiological deterioration occurring during storage, resulting in seeds with greater capacity for germination, early growth, and the formation of a vigorous shoot system and productive tillers, thereby increasing the number of spikes formed per unit area. Lower storage temperature slows biological processes and chemical reactions within the seed and reduces the rate at which stored nutrients are consumed. Differences among cultivars in spike number may also be attributed to genetic differences in their ability to produce tillers and maintain them until heading. This agrees with [14,7].

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Table 6. Effect of Storage Conditions, Cultivars, and Their Interaction on Number of Spikes (spikes m)^2)

Mean effect of storage conditions	Cultivars			Storage conditions
	Sham 6	Buhuth 22	IPA99	
403.11	429.02	376.32	404.01	**Refrigerated storage**
346.13	308.01	341.72	388.71	**Incubator storage**
371.72	391.72	369.33	354.01	**Warehouse storage**
9.26	16.04			**L.S.D. 0.05**
	376.25	362.45	382.24	**Mean effect of cultivars**
	9.26			**L.S.D. 0.05**

5- Grains per Spike (grains Number of spike^1)

The results in Table (7) showed a significant effect of storage conditions and cultivars on the number of grains per spike Refrigerated storage was .(grains spike^1) significantly superior, recording the highest compared ,grains spike 73.mean of 46 with incubator storage, which recorded^{1}the .lowest mean of 35.24 grains spike Among cultivars, Abba 99 was significantly superior, recording the highest mean of compared with Sham ,grains spike^1 43.15 west mean of 39.30 which recorded the lo ,6 For the interaction, Abba 99 .grains spike^1 under refrigerated storage recorded the highest mean number of grains per spike, compared with the ,grains spike^1 50.21 interaction of Sham 6 under incubator t mean of storage, which recorded the lowes .grains spike^1 27.20

The observed variation in the number of grains per spike under different storage conditions may be attributed to the effect of seed storage conditions on the preservation of seed viability and physiological quality. Maintaining high seed viability and germination vigor enables the resulting plants to establish vigorous vegetative growth and produce an adequate number of tillers, thereby enhancing their capacity to accumulate and translocate assimilates required for spike development, fertilization, and subsequent grain formation. Seed deterioration during storage is generally associated with progressive declines in physiological quality, germination capacity, and seedling vigor, whereas appropriate storage conditions contribute to maintaining seed viability and preserving the potential for vigorous plant establishment and subsequent growth ,The differences observed among wheat cultivars in the number of grains per spike may also be attributed to their genetic variability in yield components and their differential responses to environmental conditions. The number of grains per spike is a complex quantitative trait influenced by both genetic characteristics and environmental factors, particularly the plant's ability to maintain fertile florets and spikelets during the reproductive stages. Therefore, cultivars may differ in their capacity to form and retain fertile spikelets, resulting in variation in the final number of grains per spike. An increase in grain number per spike may be associated with a greater number of fertile spikelets and a lower proportion of degenerated or sterile spikelets, which

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ultimately contributes to improving this yield component. This agrees with(24,25).

Table 7. Effect of Storage Conditions, Cultivars, and Their Interaction on Number of Grains per Spike (grains spike)[1])

storage conditions Mean effect of	Cultivars			Storage conditions
	Sham 6	Buhuth 22	IPA99	
46.73	47.87	42.12	50.21	**Refrigerated storage**
35.24	27.20	42.77	35.77	**Incubator storage**
40.57	42.83	35.40	43.47	**Warehouse storage**
2.620	4.538			**L.S.D. 0.05**
	39.30	40.10	43.15	**effect of cultivars Mean**
	2.620			**L.S.D. 0.05**

Conclusions4-

The results of the study showed that storage conditions and storage duration had clear effects on seed traits, vegetative growth, yield components, and grain yield of the bread wheat cultivars studied. Storage at low temperature (refrigerator) ained seed viability and better maint germination capacity compared with the other storage conditions, which positively affected several growth and yield traits. In contrast, higher storage temperature, particularly incubator storage, caused a gradual decline in erformance with increasing seed p storage duration as a result of the negative effect of high temperature on seed viability and ivity. The results also,accompanied by consumption of stored nutrients and gradual deterioration of membranes and cells. in seed viability The variation resulting from storage conditions was reflected in vegetative growth and yield components, as seeds with higher viability produced better initial growth and greater capacity to .develop the shoot system

Genetic differences among cultivars were an important factor underlying their differential responses to storage conditions, confirming variation among bread wheat cultivars in their ability to tolerate storage conditions and maintain sults showed seed viability. The re that Abba 99 was superior for most traits, and the cultivar × storage condition interactions i ted that IPA99under refrigerated storage was significantly superior for most .traits

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