Journal of Applied Horticulture, 28(2): 408-414 , 2026

https://doi.org/10.37855/jah.2026.v28i02.65

Journal of Applied Horticulture

ISSN: 0972-1045

Agronomic performance and genetic parameter estimates of three onion varieties under different planting dates in a semi-arid region of Iraq

Wiam Yahya Rasheed Al-Shakarchy[1], Shamil Younis Hassan AL-Hamadany[2*], Amer Abdullah Hussein Al-Jubouri[2], Muhanad A. Ahmad[2], Badran S. Agha[2] and Ahmed Abdel Hady Rashedy[3*]

*[1]Department of Field Crops, College of Agriculture and Forestry, University of Mosul, Iraq. [2]Department of Horticulture and Landscape Design, College of Agriculture and Forestry, University of Mosul, Iraq. [3]Department of Pomology, Faculty of Agriculture, Cairo University, Egypt. *E-mail:shamil@uomosul.edu.iq*

Abstract

Iraq is ranked as the fifth-most vulnerable country to climate change. Determining the optimum planting date and the most productive onion variety is essential for maximising production and minimising the adverse effects of climate change. This study evaluated the growth, yield, and genetic parameters of three onion varieties (Long Red, Round Red, and Round White) planted on 20 February, 1 March, and 11 March during the spring season. The latest planting date (11 March) produced the lowest bulb yield. Compared with 11 March, planting on 1 March increased the bulb yields of Round Red and Round White by 95.44% and 258.4%, respectively. For Long Red, planting on 20 February produced the highest bulb yield (11.67 t ha^{-1}), representing an increase of 116.4% over the latest planting date. At their respective optimum planting dates, Long Red yielded 8.96% and 16.7% more than Round Red and Round White, respectively. Genotypic and environmental variance components were estimated for all traits. Broad-sense heritability was high for plant height, bulb length, and bulbing ratio, indicating genetic control and the potential for direct improvement of these traits in subsequent generations. Expected genetic advance as a percentage of the mean was high for bulb length, moderate for plant height, neck diameter, and bulbing ratio, and low for the remaining traits.

Keywords: *Allium cepa* L., bulb yield, genotype × planting-date interaction, semi-arid environment, climate adaptation

Introduction

Iraq has been ranked as the fifth-most vulnerable country to climate change (UNEP, 2019), owing to rising temperatures (World Bank Group, 2017), declining and increasingly variable rainfall (Karasik and Depretto, 2019), recurrent drought and water scarcity (WRI, 2015), frequent dust and sand storms (Joint Analysis and Policy Unit, 2013), and flooding (REACH and UNITAR, 2020). Identifying the optimum planting date and the most productive onion variety is therefore essential for maximising production under increasingly adverse climatic conditions. Water policies in neighbouring countries have also reduced access to essential water resources (Dockx, 2019), while population growth and inefficient agricultural water use continue to increase demand (Von Lossow, 2018). These challenges highlight the need to identify efficient variety–planting-date combinations. Onion productivity is influenced by variety (Rahaman *et al.*, 2021), fertilisation (Kumar *et al.*, 2025; 2026; Bhardwaj and Parashar, 2023), irrigation and soil mulching (Jat *et al.*, 2025), and planting date (Aboukhadrah *et al.*, 2017).

Planting date is a major determinant of crop performance. In onion, excessively early planting may increase flowering or bolting at the expense of bulb yield (Khokhar, 2014). Local varieties are often preferred because of their nutritional value, storage and transport tolerance, and adaptation to local environmental conditions; among Iraqi onions, Long Red is considered particularly important (Mohammed, 1983). Planting-date effects have also been reported in several crops. In Egypt, planting wheat on 15 November produced greater growth and yield than planting on 15 December (Mostafa *et al.*, 2025). In sugar beet, sowing on 1 September increased plant dry weight, leaf area, root weight, and sucrose percentage relative to sowing on 1 October or 1 November, and Natura was the most productive variety under North Sinai conditions (Eldin Zaki *et al.*, 2025). Early sowing also improved the growth and yield of canola (Soliman, 2025). For Giza Red onion, planting on 15 December was more effective than planting on 1 or 15 January and produced the greatest plant height, leaf area, bulb weight, and total yield (Aboukhadrah *et al.*, 2017). Gerami *et al.* (2018) similarly found that planting date significantly affected most traits of oregano (*Origanum vulgare* L.), with the earliest date generally producing the highest values.

Understanding genetic variation is essential for crop improvement because it enables breeders to identify traits that can respond effectively to selection. Phenotypic variation can be partitioned into environmental variance, in which genetically similar plants differ because of environmental effects (Al-Mufarji, 2006), and genotypic variance, which reflects differences among genetic constitutions (Al-Sahouki, 1990). Trait expression is therefore determined by both genotype and environment. Heritability quantifies the proportion of phenotypic variation attributable to genetic effects and is an important guide for selecting appropriate breeding methods. Accordingly, the present study aimed to evaluate the growth and yield of three onion varieties under different planting dates in Iraq and to estimate genotypic, phenotypic, and environmental variances; coefficients of variation; broad-sense heritability; and expected genetic advance for yield-related traits.

Materials and methods

Experimental site: The experiment was conducted in 2025 in the vegetable field of the Department of Horticulture and Landscape Engineering, College of Agriculture and Forestry, University of Mosul, Mosul, Iraq (36.35° N, 43.15° E; 223 m above sea level) (Guest, 1966). Climatic conditions during the experiment are presented in Table 1.

Table 1. Monthly climatic variables (temperature, relative humidity, and rainfall) at the experimental site during 2025

Month	L	H	A	RH	R
February	4.2	10.39	7.29	83.4	52.1
March	6.38	13.8	10.09	80.6	80.6
April	9.31	20.8	15.05	74.4	81.3
May	13.25	24.91	19.08	79.0	147.9
June	23.43	41.36	32.39	77.7	129.3

Source: Meteorological Station in Al-Rashidiya, Mosul, Iraq. Values are monthly means. L = minimum temperature (°C); H = maximum temperature (°C); A = mean temperature (°C); RH = relative humidity (%); R = rainfall (mm).

Soil sampling and analysis: Before planting, soil samples were collected from a depth of 0–25 cm and analysed for physical and chemical properties following Sparks *et al.* (1996) and Dane and Topp (2020). The results are presented in Table 2.

Table 2. Physical and chemical properties of the experimental soil.

Property and Unit	Value
Soil pH	7.01
Electrical Conductivity (EC) (dS m^{-1})	1.80
Organic Matter (%)	1.40
Available Nutrient Content	
Nitrogen (mg kg^{-1})	50
Phosphorus (mg kg^{-1})	15.00
Potassium (mg kg^{-1})	180
Soil particle size distribution	
Sand (%)	55.55
Silt (%)	23.75
Clay (%)	20.70
Soil Texture	Sandy loam

Treatments: Three onion varieties—Long Red, Round Red, and Round White—were evaluated at three planting dates: 20 February 2025, 1 March 2025, and 11 March 2025. Uniform bulbs or seedlings of the three onion cultivars were established (10–15 mm diameter, 40 days old) in 3-m-long rows, with 8.1 cm between plants and 70 cm between rows, approximately 176,000 plants ha^{-1}. The Nursery of the University of Mosul, Iraq, confirmed the varietal identities of the three onion cultivars. Healthy, uniform seedlings approximately one month of age were supplied by the nursery and transplanted into the experimental field. Total bulb yield was determined by directly weighing all marketable bulbs harvested from the net plot and converting the values to t ha^{-1}.

Experimental design: The experiment was arranged as a 3 × 3 factorial in a randomised complete block design with three replications, giving 27 experimental plots. Each plot consisted of two 3-m-long rows. All treatments received the same irrigation. Fertilisation of NPK rates were 214 kg N ha^{-1}, 143 kg P_2O_5 ha^{-1}, and 114 kg K_2O ha^{-1}, applied from ammonium sulfate (20.5% N), single superphosphate (15% P_2O_5) and potassium sulfate (48% K_2O). Before planting, the full phosphorus dose was incorporated into the soil. In contrast, nitrogen and potassium were each applied in two equal splits: the first 15 days after planting and the second two weeks later. Weed control (hand weeding) and pest-management practices were used throughout the experimental period.

Plant measurements: Harvest maturity was determined from physiological indicators, including 50–80% neck fall, cessation of new leaf production and bulb enlargement, yellowing of the foliage, and formation of cultivar-specific bulb scales. Long Red, Round White, and Round Red were harvested 120, 110, and 95 days after planting, respectively. At harvest, plant height and bulb length were measured, and the number of leaves per plant was counted. Neck diameter and bulb diameter were measured using a digital calliper. Leaf area was estimated using the following equation described by Corcoles *et al.* (2015):

$$\text{Leaf area } (\text{cm}^2\ \text{plant}^{-1}) = 0.000199 + 1.277(L \times A_{25})$$

where L is total leaf length and A_{25} is leaf diameter measured at 25% of total leaf length. The original work developed this as an estimate of individual onion-leaf area. The estimated areas of all leaves were summed to obtain total leaf area per plant.

The bulbing ratio was calculated as the ratio of neck diameter to maximum bulb diameter (ND/BD). Bulb weight was recorded in g $plant^{-1}$. Total yield (TY, t ha^{-1}) was calculated from average bulb weight (ABW) and the number of plants per hectare (NPH) as follows:

$$TY = (ABW \times NPH) / 1{,}000{,}000$$

Phenotypic, genotypic, and environmental variances, together with the phenotypic and genotypic coefficients of variation, were estimated following Steel and Torrie (1980):

$$\sigma^2_P = \sigma^2_G + \sigma^2_E$$

$$\sigma^2_G = (MS_V - MS_E) / (R \times B)$$

$$\sigma^2_E = MS_E$$

where σ^2P is the phenotypic variance, σ^2G is the genotypic variance, σ^2E is the environmental variance, MSV is the mean square for variety, and MSE is the experimental-error mean square.

R is the number of replications and B is the number of planting dates (B = 3).

$$PCV\ (\%) = [\sqrt{(\sigma^2_P)} / \bar{X}] \times 100$$

where $\bar{X}$ is the arithmetic mean of the trait.

$$GCV\ (\%) = [\sqrt{(\sigma^2_G)} / \bar{X}] \times 100$$

where GCV and PCV are the genotypic and phenotypic coefficients of variation, respectively.

$$H^2_{(bs)} = (\sigma^2_G / \sigma^2_P) \times 100$$

Broad-sense heritability was estimated following Johnson *et al.* (1955). Expected genetic advance (EGA) was estimated following Kempthorne (1969):

$$EGA = K \times \sigma_P \times H^2_{(bs)}, \text{ where } \sigma_P = \sqrt{(\sigma^2_P)}$$

Here, K = 2.06, corresponding to a selection intensity of 5%, and $H^2(bs)$ is expressed as a proportion. Expected genetic advance as a percentage of the mean was calculated as:

$$EGA\ (\%) = (EGA / \bar{X}) \times 100$$

Table 3. Mean squares from the analysis of variance for the studied onion traits

SV	R	V	D	V × D	E
df	2	2	2	4	16
		Mean squares (MS)			
PH	4.398	178.064**	444.287**	112.87**	7.773
NL	0.148	1.953*	20.398**	1.703*	0.439
LA	250.288	9842.71	252782.037**	40529.347**	4412.911
BW	25.148	259.148*	2774.037**	285.175*	76.658
BL	0.528	33.955**	3.319**	2.227**	0.329
BD	0.013	0.138*	2.639**	1.046**	0.05
ND	0.002	0.172**	0.804**	0.131**	0.027
BR	0.0012	0.0114**	0.0159**	0.0050**	0.0004
TY	0.778 ns	8.027 ns*	85.928**	8.833*	2.374 ns

*, ** Significant at $P \leq 0.05$ and $P \leq 0.01$, respectively. SV = source of variation; R = replication; V = variety; D = planting date; V × D = variety × planting date interaction; E = experimental error; df = degrees of freedom; MS = mean square; PH = plant height; NL = number of leaves plant^{-1}; LA = leaf area (cm^2 plant^{-1}); BW = bulb weight (g plant^{-1}); BL = bulb length (cm); BD = bulb diameter (cm); ND = neck diameter (cm); BR = bulbing ratio; TY = total yield (t ha^{-1}).

Statistical analysis: Data from 10 randomly selected plants per experimental unit were analysed using SAS (2017) software, version 9.4 (SAS Institute Inc., Cary, NC, USA). Treatment means were separated using Duncan's multiple range test at $P \leq 0.05$. Blocks were treated as random. Variety and planting date were fixed. Residual normality and variance homogeneity were tested. Analyses were conducted on plot means. The exact SAS procedure was specified.

Results and discussion

Analysis of variance: The analysis of variance showed significant differences among the three varieties for all traits except leaf area (Table 3). Variety significantly affected plant height, number of leaves per plant, bulb length, neck diameter, and bulbing ratio. However, varietal effects on leaf area, bulb weight, bulb diameter, and total yield were not significant at $P \leq 0.05$. This variation provides useful genetic material for selecting superior genotypes and developing improved onion cultivars.

Planting date significantly affected all studied traits at $P \leq 0.01$. The variety × planting date interaction was significant at $P \leq 0.05$ for number of leaves per plant, bulb weight, and total yield and at $P \leq 0.01$ for the remaining traits, demonstrating that varietal performance depended on planting date. This interaction should therefore be considered in genotype selection and future breeding programmes. Similar varietal differences in onion growth and yield traits have been reported by Tegbew *et al.* (2018), Gosai *et al.* (2018), Hidayatullah *et al.* (2018), Manjunath and Hiremath (2022), Surbhi *et al.* (2024), Chavan *et al.* (2024), and Rajshree *et al.* (2025).

Table 4. Effects of onion variety on the studied traits

Variety	Traits								
	PH	NL	LA	BW	BL	BD	ND	BR	TY
V1	46.667a	7.388b	344.57a	64.10a	7.766a	4.180b	1.400a	0.329a	9.152a
V2	44.500a	8.166a	393.43a	43.44ab	4.372b	4.427a	1.172b	0.268b	7.646ab
V3	38.111b	8.222a	330.40a	42.111b	4.433b	4.305ab	1.150b	0.266b	7.411b

Means followed by the same letter within a column do not differ significantly according to Duncan's multiple range test at $P \leq 0.05$. V1 = Long Red; V2 = Round Red; V3 = Round White. Abbreviations for the traits studied are provided below Table 3.

Table 5. Effects of planting date on the studied onion traits

Date	Traits								
	PH	NL	LA	BW	BL	BD	ND	BR	TY
D1	41.667b	7.777b	327.47b	52.778a	5.944a	4.505a	1.494a	0.333a	9.288a
D2	50.722a	9.500a	536.21a	58.889a	5.800a	4.716a	1.316b	0.281b	10.364a
D3	36.889c	6.500c	204.72c	25.889b	4.827b	3.691b	0.911c	0.249c	4.556b

Means followed by the same letter within a column do not differ significantly according to Duncan's multiple range test at $P \leq 0.05$. D1 = 20 February; D2 = 1 March; D3 = 11 March. Abbreviations for the traits studied are provided below Table 3.

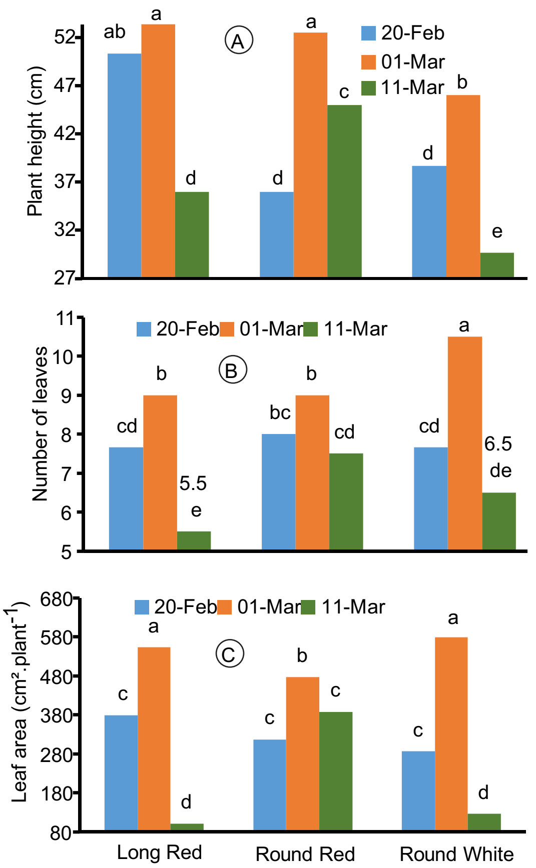

Fig. 1. Effects of planting date on plant height (A), number of leaves per plant (B), and leaf area (C) of three onion varieties (Long Red, Round Red, and Round White).

Effect of onion variety: Round White had the lowest plant height, whereas Long Red and Round Red did not differ significantly for this trait (Table 4). Long Red produced the fewest leaves per plant. Leaf area did not differ significantly among varieties. Long Red produced the greatest bulb weight and bulb length, while Round Red had a larger bulb diameter than Long Red. Long Red also had the greatest neck diameter, bulbing ratio, and total yield. These differences likely reflect genetic variation among the varieties and their responses to the local environment (Al-Jassem, 2022). Comparable genotype-dependent differences in growth and yield have been reported for sugar beet (Eldin Zaki *et al.*, 2025) and quinoa (Awadalla and Morsy, 2017).

Effect of planting date: Plants established on 1 March had the greatest plant height, number of leaves, leaf area, bulb weight, bulb diameter, and total yield, whereas those planted on 11 March had the lowest values for these traits (Table 5).

For bulb weight, bulb length, bulb diameter, and total yield, the 1 March treatment did not differ significantly from 20 February. Planting on 20 February produced the greatest neck diameter and bulbing ratio. The superior performance of the earlier planting dates was probably associated with a longer growth period and more favourable temperature and light conditions for photosynthesis

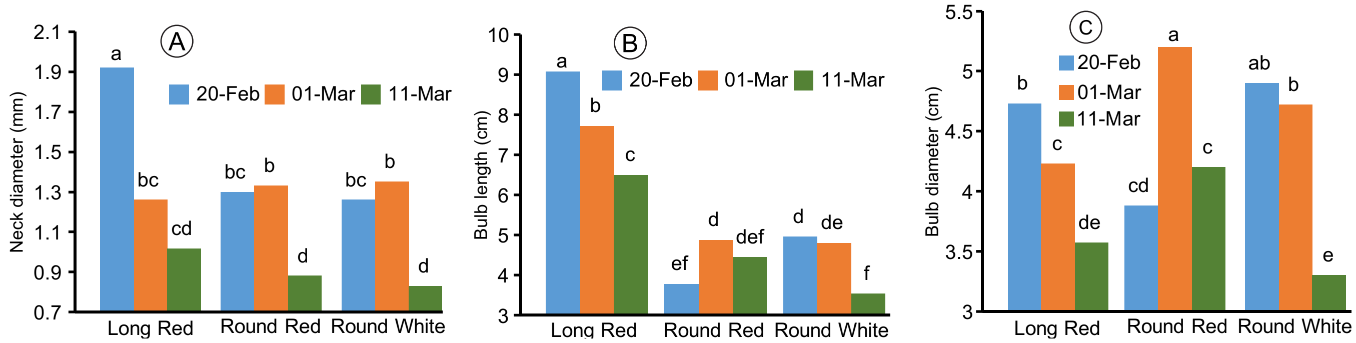

Fig. 2. Effects of planting date on neck diameter (A), bulb length (B), and bulb diameter (C) of three onion varieties.

(Salari *et al.*, 2021). Similar planting-date responses have been reported for Giza Red onion (Aboukhadrah *et al.*, 2017), cotton (Mahdi *et al.*, 2019), sugar beet (Eldin Zaki *et al.*, 2025), wheat (Mostafa *et al.*, 2025), canola (Soliman, 2025), cluster bean (Zubair *et al.*, 2022), and cowpea (Elsobky and Hassan, 2021).

Interaction effects: All three varieties attained their greatest plant height when planted on 1 March (Fig. 1A). Long Red and Round White had their lowest plant heights when planted on 11 March, whereas Round Red had its lowest value on 20 February. Round White planted on 1 March produced the greatest number of leaves and leaf area (Fig. 1B, C).

The lowest number of leaves and leaf area were recorded for Long Red planted on 11 March. These responses confirm that vegetative growth was strongly influenced by the variety × planting date interaction.

For neck diameter, Long Red recorded its highest value when planted on 20 February, whereas Round Red and Round White recorded their highest values on 1 March (Fig. 2A). All varieties had their lowest neck diameter when planted on 11 March.

Long Red consistently produced the longest bulbs across the three planting dates (Fig. 2B). The maximum bulb diameter was recorded for Round Red planted on 1 March, while Round White produced its largest bulb diameter on 20 February (Fig. 2C). Overall, the longest bulb occurred in Long Red planted on 20 February. In contrast, the shortest bulb occurred in Round White planted on 11 March.

The highest bulbing ratio was recorded for Long Red planted on 20 February, followed by Round Red at the same planting date (Fig. 3A). In general, the bulbing ratio declined as planting was delayed. For bulb weight and total yield, Long Red performed best when planted on 20 February, whereas Round Red and Round White performed best when planted on 1 March (Fig. 3B, C). Planting on 11 March reduced bulb weight and yield in all varieties, with the lowest values recorded for Round White.

Genetic variability is essential for selecting superior genotypes in crop-improvement programmes. Because agronomic traits are quantitative and strongly influenced by the environment, partitioning phenotypic variation into genotypic and environmental components helps identify the heritable portion of variability (Sarker *et al.*, 2015). Significant varietal and planting-date effects have also been reported in sugar beet (Eldin Zaki *et al.*, 2025), wheat (Mostafa *et al.*, 2025), canola (Soliman, 2025), cluster bean (Zubair *et al.*, 2022), cowpea (Elsobky and Hassan, 2021), and cotton (Mahdi *et al.*, 2019). The present findings agree with Aboukhadrah *et al.* (2017), who found that earlier planting improved the growth and yield of Giza Red onion, and with genotype-specific planting-date responses reported for quinoa (Awadalla and Morsy, 2017) and sugar beet (Eldin Zaki *et al.*, 2025). At their respective optimum planting dates, Long Red yielded 8.96% and 16.7% more than Round Red and Round White, respectively.

The latest planting date (11 March) produced the lowest bulb yields. Relative to this date, planting on 1 March increased the yields of Round Red and Round White by 95.44% and 258.4%, respectively. For Long Red, planting on 20 February produced the highest yield (11.67 t ha^{-1}), which was 116.4% greater than the yield obtained from planting on 11 March.

Table 6 summarises the trait means, variance components, and genetic parameters. Genotypic and environmental variance components were estimated for all traits. These findings are consistent with reports of substantial genetic

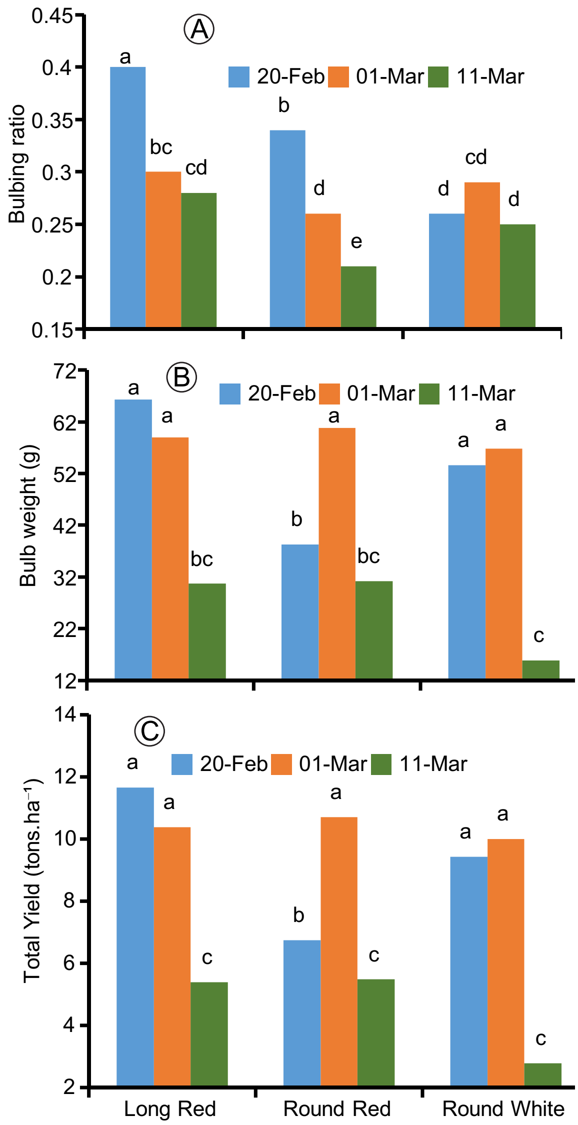

Fig. 3. Effects of planting date on bulbing ratio (A), bulb weight (B), and total yield (C) of three onion varieties (Long Red, Round Red, and Round White).

Table 6. Trait means, variance components, and genetic parameters for the studied onion traits

GP	PH	NL	LA	BW	BL	BD	ND	BR	TY
GV	18.921	0.168	603.311	20.276	3.736	0.009	0.016	0.0012	0.628
EV	7.773	0.439	4412.911	76.658	0.329	0.050	0.027	0.0004	2.374
PV	26.694	0.607	5016.222	96.934	4.065	0.059	0.043	0.0016	3.002
GCV	10.094	5.175	6.896	9.820	34.990	2.204	10.200	12.0239	9.821
PCV	11.989	9.831	19.887	21.472	36.499	5.643	16.722	13.8840	21.473
HBS	70.80	27.70	12.00	20.90	91.90	15.20	37.20	75.00	20.90
EGA	7.535	0.444	17.508	4.238	3.817	0.076	0.159	0.0618	0.746
EGA%	17.485	5.603	4.916	9.242	69.098	1.765	12.823	21.4509	9.245
GA	43.092	7.925	356.134	45.851	5.524	4.304	1.240	0.2881	8.069

GV = genotypic variance; EV = environmental variance; PV = phenotypic variance; GCV = genotypic coefficient of variation; PCV = phenotypic coefficient of variation; HBS = broad-sense heritability; EGA = expected genetic advance; EGA% = expected genetic advance as a percentage of the mean; GA = general average. Abbreviations for the traits studied are provided below Table 3.

and environmental variation in onion by Rajya (2015), Pravin *et al.* (2017), Pushpa *et al.* (2023), Chavan *et al.* (2024), and Rajshree *et al.* (2025).

Environmental variance exceeded genotypic variance for number of leaves per plant, leaf area, bulb weight, bulb diameter, neck diameter, and total yield. In contrast, genotypic variance exceeded environmental variance for plant height, bulb length, and bulbing ratio.

Bulb length had the highest genotypic and phenotypic coefficients of variation, whereas bulb diameter had the lowest. Comparable patterns of variability have been reported by Mukesh and Balaji (2017), Santra *et al.* (2017), Manjunath and Hiremath (2022), Khosa and Dhatt (2024), and Surbhi *et al.* (2024). Because many of these traits are quantitatively inherited and environmentally sensitive, selection should be based on replicated evaluations across relevant environments rather than on phenotype alone (Al-Mukhtar, 1988).

The phenotypic coefficient of variation exceeded the genotypic coefficient of variation for every trait, indicating that planting date and other environmental factors contributed substantially to the observed phenotypic variability.

Broad-sense heritability ranged from 0.120 for leaf area to 0.919 for bulb length. Heritability was high for plant height, bulb length, and bulbing ratio and low to moderate for the remaining traits.

High broad-sense heritability indicates that genetic effects account for a large proportion of the observed phenotypic variance, although it does not distinguish additive from non-additive effects (Mather and Jinks, 1982). Traits with high heritability may therefore respond favourably to selection and can help guide the choice of breeding method (Allard, 1960). Similar high heritability estimates have been reported by Antonio *et al.* (2017), Manjunath and Hiremath (2022), Rahul *et al.* (2023), Chavan *et al.* (2024), and Rajshree *et al.* (2025). However, because the variety × planting date interaction was significant for several traits, these estimates should be interpreted within the tested environment and planting-date range rather than as universally stable genetic parameters.

Expected genetic advance as a percentage of the mean ranged from 1.765% for bulb diameter to 69.098% for bulb length. It was high for bulb length and bulbing ratio, moderate for plant height and neck diameter, and low for the remaining traits. These findings agree with Gaurav *et al.* (2017), Pushpendra *et al.* (2017), Tripathy and Sahoo (2018), Islam *et al.* (2019), Chandel *et al.* (2024), and Chavan *et al.* (2024). High broad-sense heritability combined with high expected genetic advance may indicate useful genetic variability; however, the present design does not permit separation of additive and non-additive genetic effects. Visscher *et al.* (2008) is useful for explaining the conditional nature of heritability, but it does not directly validate the present inference about additive gene action.

Under the semi-arid conditions of Mosul, onion growth and yield were significantly influenced by variety, planting date, and their interaction. Planting on 11 March consistently reduced growth and bulb yield. The optimum date was 1 March for Round Red and Round White and 20 February for Long Red, which produced the highest yield (11.67 t ha^{-1}). These findings support matching onion varieties with suitable spring planting dates to improve productivity; however, validation across additional years and locations is required.

References

Aboukhadrah, S.H., A.W.A.H, El-Alsayed, L. Sobhy, and W. Abdelmasieh, 2017. Response of onion yield and quality to different planting date, methods and density. *Egypt. J. Agron.,* 39(2), 203–219Aboukhadrah, S.H., A.W.A.H, El-Alsayed, L. Sobhy, and W. Abdelmasieh, 2017. Response of onion yield and quality to different planting date, methods and density. *Egypt. J. Agron.,* 39(2), 203–219. doi: 10.21608/AGRO.2017.1203.1065

Al-Jassem, A. 2022. Evaluation of some introduced onion varieties (*Allium cepa* L.) in terms of growth, morphological characteristics, productivity, and cultivation by seedling method. *Syrian J. Agric. Res.,* 9 (4): 103–114.

Allard, R.W. 1960. Principles of Plant Breeding. John Wiley and Sons. Inc., New York, USA.

Al-Mufarji, O.K.A. 2006. *Analysis of Combination Ability and Estimation of Hybrid Strength and Genetic Parameters in Okra* (*Abelmoschus esculentus* L.). PhD Dissertation, College of Agriculture – University of Baghdad – Iraq.

Al-Mukhtar, F.A-H. 1988. Genetics and Breeding of Horticultural Plants. Ministry of Higher Education and Scientific Research – University of Baghdad – House of Wisdom, Baghdad – Iraq.

Al-Sahouki, M.M. 1990. Yellow Corn: Production and Improvement. Higher Education Press, Baghdad.

Antonio, E.S., C.A. Santos, L.N. da Luz, V.R. Oliveria, J.A. Candeia and J.L. Filho, 2017. Genetic gain of 'Valenciana' onion populations developed in the Brazilian Semi-Arid region. *Crop Breed. Appl. Biotechnol.*, 17: 168–174. https://doi.org/10.1590/1984–70332017v17n2n25

Awadalla, A., A.S. and Morsy, 2017. Influence of planting dates and nitrogen fertilization on the performance of quinoa genotypes under Toshka conditions. *Egypt. J. Agron., 39*(1), 27–40. doi: 10.21608/agro.2017.440.1047.

Bhardwaj, R.L. and A. Parashar, 2023. Maximizing productivity in onion bulb cultivation through crop geometry and NPKS nutrient management. *J. Appl. Hortic*., 25(3): 308–312. doi: 10.37855/jah.2023.v25i03.20

Chavan, S., S.M. Hiremath, G. Doggalli, V. Patil, S.M. Ajay, M.A. Vernekar and V.K. Pn 2024. Assessment of Genetic Variability, Heritability and Genetic Advance in White Onion (*Allium cepa* L.) for Growth, Bulb Yield, Quality and its Component Characteristics. *J. Adv. Biol. Biotechnol*., 27(9): 1194–1199. doi: 10.9734/JABB/2024/10.9734/jabb/2024/v27i91389

Corcoles, J.I., A. Dominguez, M.A. Moreno, J.F. Ortega and J.A. de Juan 2015. A non–destructive method for estimating onion leaf area. *Irish J. Agric. Food Res.*, 54(1), 17 -30. https://doi.org/10.1515/ijafr-2015–0002

Dane, J.H. and C.G. Topp (Eds.), 2020. Methods of Soil Analysis, Part 4: Physical methods (Vol. 20). John Wiley & Sons.

Dockx, P.J. 2019. *Water scarcity in Iraq*. Institute of Peace and Conflict Studies (IPCS). Available at: http://www.ipcs.org/issue_briefs/issue_brief_pdf/ipcssr203_contested%20waters%20project_water%20scarcity%20in%20iraq_p%20jan-dockx_may%202019.pdf.

Eldin Zaki, M., B. Ramadan, M. Hassanin, E. Mahmoud, K. El Afendy, 2025. Effect of sowing date and plant density on productivity of some sugar beet varieties under North Sinai Conditions. *Egyp. J. Agron.*, *47*(3), 373–380. doi: 10.21608/agro.2025.368827.1427

Elsobky, E.E. and H.H. Hassan, 2021. Optimizing cowpea productivity by sowing date and plant density to mitigate climatic changes. *Egypt. J. Agron.,* 43(3), 317–331. doi: 10.21608/agro.2021.64386.1238

Gaurav, S., V. Balaji and V.M. Prasad, 2017. Studies on multiple correlation between bulb yield, growth and yield attributes in different genotypes of onion (*Allium cepa* L.) under Allahabad Agro-Climatic Condition. *J. Pharmacogn. Phytochem.,* 6(6): 793–798.

Gerami, F., P.R. Moghaddam, R. Ghorbani and A. Hassani, 2018. Influence of planting date and plant density on morphological characteristics, seed yield and essential oil percentage of oregano (*Origanum vulgare* L.). *J. Appl. Hortic.,* 20(3): 171–176.

Gosai, J.A., S.N. Rathawa, R.K. Dhakad, A. Jatav and L.R. Verma, 2018. Evaluation of different varieties of onion (*Allium cepa* L.) under North Gujarat condition. *Int. J. Curr. Microbiol. App. Sci.*, 7(5): 3775–3780.

Guest, A. 1966. Flora of Iraq. Ministry of Agric. Republic of Iraq. 1: 21.

Hidayatullah, H.A. Khan and G. Jillani, 2018. Response of two newly selected onion strains at different plant populations. *Hortic. Int. J.*, 2(1): 17–19.

Jat, A., S.K. Moond, S. Choudhary, M. Ram and L.N. Netajit, 2025. Quality and nutrient uptake of onion (*Allium cepa* L.) as influenced by water regimes, land configurations and mulching. *Indian J. Agric. Res.*, 59(12), 1876–1881. doi: 10.18805/IJARe.A-6306.

Johnson, C.H., H.F. Robinson and R.E. Comstock, 1955. Estimates of genetic and environmental variability in soybean. *Agron. J.*, 47: 314–318.

Joint Analysis and Policy Unit (JA and PU). 2013. Sand and Dust Storms Fact Sheet. UN Iraq. Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/SDS%20Fact%20Sheet.pdf.

Karasik, T. and J.S. Depretto, 2019. Climate change is exacerbating Iraq's complicated water politics. Climate Diplomacy. Accessed 15 May, 2026. Available at: https://climate-diplomacy.org/magazine/environment/climate-change-exacerbating-iraqs-complicated-water-politics.

Kempthorne, B. 1969. An Introduction to Genetic Statistics. Ames, Iowa State University Press.

Khokhar, K. 2014. Flowering and seed development in onion—a review. *Open Access Library J.*, 1, 1–13. doi: 10.4236/oalib.1101049.

Khosa, J.S. and A.S. Dhatt, 2024. Studies on Genetic Variability and Heritability in Bulb Onion (*Allium cepa* L.) in North-Western Plains of India. *J. Hortic. Sci,* 8(2):314.

Mahdi, A., H. Khalifa and R. Taha, 2019. Performance evaluation of three Egyptian cotton genotypes under different thermal units related to different planting dates. *Egyp. J. Agron., 41*(2), 149–158. https://doi.org/10.21608/agro.2019.12006.1162

Manjunath, U. and S.M. Hiremath, 2022. Genetic variability, heritability and genetic advance in onion (*Allium cepa* L.) for bulb yield and its component characters. *Pharma Innov.*, 11: 2570–2572.

Mather, K. and J.L. Jinks, 1982. Biometrical Genetics. 3rd ed. Chapman and Hall Ltd. London.

Matloub, A.N., S.M. Ezz El-Din and S.A. Karim, 1989. Vegetable Production (Part Two). Ministry of Higher Education and Scientific Research - University of Mosul.

Mohammed, E.S. 1983. Vegetable Seed Production. Ministry of Higher Education and Scientific Research - University of Mosul. Iraq.

Mostafa, A., A. Hussein, M. Elsayed and E. Hussein, 2025. Diminishing impacts of water deficit and heat stress on bread wheat via screening some genotypes and different planting dates. *Egypt. J. Agron., 47*(4), 1127–1148. doi: 10.21608/agro.2025.398790.1737.

Mukesh, K.J. and V. Balaji, 2017. Genetic variability in different genotypes of onion (*Allium cepa* L.). *Res. Environ. Life Sci.*, 10(2): 166–169.

Pravin, K.S., A. Singh, D.S. Duhan, N. Kishor and N.S. Barar, 2017. Genetic Variability, Heritability and Genetic Advance in Onion (*Allium cepa* var. Cepa L.). *Int. J. Pure. App. Biosci*., 5(6): 740–743. http://dx.doi.org/10.18782/2320-7051.6044.

Pushpa, H., B. Patil, R. Gunnaiah, S. Cholin and Ambresh, 2023. Estimates of variability, heritability, genetic advance for yield and its quality traits in onion (*Allium cepa* L.) genotypes. *Int. J. Environ. Clim. Chang.*, 13(10):1758–1770.

Pushpendra, S., A.K. Sony, P. Diwaker, A.R. Meena and D. Sharma, 2017. Genetic Variability Assessment in Onion (*Allium cepa* L.) Genotypes. *Int. J. Chem. Stud.*, 5(5): 145–149.

Rahaman S., J. Mandal and S. Mohanta, 2021. Field performance and storage losses of onion (*Allium cepa* L.) under the Coastal Saline Zone of West Bengal. *J. Appl. Hortic*., 23(2): 188–192.

Rahul, C., S. Singh, A. Kumar, Y. Taak and A. Khar, 2023. Genetic diversity of morphological, biochemical and mineral traits in Indian onion (*Allium cepa*) genotypes. *Indian J. Agric. Sci.,* 94(6):140320.

Rajshree, G., K. Gangte, J. Trivedi and N. Kiran, 2025. Genetic variability and character association analysis in White onion (*Allium cepa* L.) genotypes. *Int. J. Adv. Biochem. Res.,* 9, Special Issue9, Part L (2025). URL:https://www.biochemjournal.com/specialissue/2025.v9.i9S.L.5618/genetic-variability-and-character-association-analysis-in-white-onion-allium-cepa-l-genotypes.

Rajya, R.L. 2015. Studies on genetic variability, correlation and path analysis of yield and yield components in onion. *J. Hortic. Sci.*, 10(2): 237–241. https://doi.org/10.24154/jhs.v10i2.137.

REACH & United Nations Institute for Training and Research (UNITAR). 2020. *Flood hotspots in Iraq (October 2018–March 2019). Accessed 1 June, 2026.* Available at: https://www.impact-repository.org/document/reach/19ad1c82/REACH_IRQ_Factsheet_Flooding_trends_in_Iraq.pdf.

Sabina, I., A. Khar, S. Singh and B.S. Tomar, 2023.Variability, heritability and trait association studies for bulb and antioxidant traits in onion (*Allium cepa*) varieties. *Indian J. Agric. Sci.*, 89(3):87588.

Salari, H., R.S. Antil and Y.S. Saharawat, 2021. Responses of onion growth and yield to different planting dates and land management practices. *Agron. Res.,* 19(4), 1914–1928.

Santra, P., D. Manna, H.K. Sarkar and T.K. Maity, 2017. Genetic variability, heritability and genetic advance in Kharif onion (*Allium cepa* L.). *J. Crop Weed*, 13(1): 103–106.

Sarker, U., M.T. Islam, M.G. Rabbani and S. Oba, 2015. Variability, heritability and genetic association in vegetable amaranth (*Amaranthus tricolor* L.). *Spanish Journal of Agricultural Research, 13*(2), e0702. https://doi.org/10.5424/sjar/2015132-6843

SAS (2017). Statistical Analysis System. SAS Institute, Inc., Cary, NC, 27511, USA.

Soliman, D. 2025. "Optimizing Canola Cultivation through Adaptive Planting Dates and Nano-Bio Fertilization for Sustainable Yields". *Egypt. J. Agron.,* 47(3), 393–403.

Sparks, D.L., A.L. Page, P.A. Helmke and R.H. Loeppert (Eds.), 2020. Methods of Soil Analysis, Part 3: Chemical Methods. John Wiley & Sons. https://doi.org/10.2136/sssabookser5.3.

Steel, R.G.D. and J. Torrie, 1980. Principles and Procedures of Statistics. 2nd, McGraw-Hill Book Co. Inc. London, p. 560.

Sujanthiya, P., A. Sankari, H. Usha Nandhini Devi, M. Djanaguiraman, R. Kalaiyarasi and G. Dheebakaran, 2024. Untargeted metabolite profiling of *Aggregatum* onion cultivars: Insights from GC-MS-based metabolomics studies. *J. Appl. Hortic*., 26(2): 206–211.

Surbhi, S., K.D. Ameta, B.G. Chhipa, R.B. Dubey and V. Saharan, 2024. Genetic variability analysis in onion (*Allium cepa* L.) genotypes. *Indian J. Arid Hortic.,* 6(1): 16401. https://doi.org/10.48165/ijah.2024.6.1.8.

Tegbew, W., D. Nigussie and W. Kebede, 2018. Yield and Yield Components of Onion (*Allium cepa* var. cepa) Cultivars as Influenced by Population Density at Bir Sheleko, North-Western Ethiopia. *Acad. Res. J. Agric. Sci. Res.,* 6(3): 172–192.

Von Lossow, T. 2018. More than infrastructure: Water challenges in Iraq. Clingendael Institute. Available at: https://www.clingendael.org/publication/more-infrastructures-water-challenges-iraq.

Tripathy T. and B.B. Sahoo 2018. Genetic variability, heritability and genetic advancement in rabi onion (*Allium cepa* L.). *J. Allium Res*., 1(1): 37–40.

United Nations Environment Programme (UNEP). 2019. Global Environment Outlook 6: Healthy Planet, Healthy People. UNEP. Accessed 1 May 2026. https://www.unep.org/resources/global-environment-outlook-6.

Visscher, P.M., W.G. Hill and N.R. Wray, 2008. Heritability in the genomics era—concepts and misconceptions. *Nat. Rev. Genet.*, 9(4): 255–266.

World Bank Group. 2017. Iraq systematic country diagnostic (Report No. 112333-IQ). World Bank Group. Accessed 1 May 2026. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/542811487277729890/iraq-systematic-country-diagnostic.

World Resources Institute (WRI). 2015. Ranking the world's most water-stressed countries in 2040. Accessed 15 May 2026. https://www.wri.org/insights/ranking-worlds-most-water-stressed-countries-2040.

Yaman, K., V. Tripathi and D. Verma, 2026. Field application of nanoparticles along with curing for shelf-life extension in onion. *J. Appl. Hortic*., 28(1): 129–134. doi: 10.37855/jah.2026.v28i01.19

Yaman, K., V. Tripathi, D. Verma, V.D., Goutam, A., Bhardwaj and A. Kumari, 2025. Enhancing growth, yield and quality traits of onion (*Allium cepa* L.) through humic acid and sulphur nanoparticle applications. *J. Appl. Hortic*., 27(4): 600–605.

Zubair, M., R. Minhas, M.I. Akram, M. Rehman, M.M. Khan, M.S. Bukhari, S. Hussain, R. Ullah, I. Akhtar, S.W. Hussain and S.U. Rehman, 2022. The appropriate sowing time and plant density to achieve a higher yield of cluster beans. *Egypt. J. Agron.,* 44(2), 163–171. doi: 10.21608/agro.2022.142606.1323.

Received: March, 2026; Revised: April, 2026;
Accepted: May, 2026