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FIELD YIELD AND TRAIT-SPECIFIC SEEDLING RESPONSES GUIDE WINTER WHEAT GERMPLASM SELECTION IN UZBEKISTAN

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Abstract: Selecting wheat breeding material for irrigated environments requires empirical evidence on grain yield and early growth under adverse conditions. We evaluated complementary datasets from Gallaorol, Uzbekistan: a 2025 field yield panel of 11 winter bread wheat entries, separate collection assays using sucrose (11 entries) and NaCl (10 entries), and an advanced breeding panel comprising 10 genotypes with complete data assessed for four seedling traits during 2024–2026. Field yield was analysed using the reported one-factor analysis of variance; laboratory responses were evaluated descriptively from treatment means. Yield ranged from 5.237 to 6.797 t ha^{-1}, and six accessions exceeded Zamin-1 using a protected Fisher least significant difference of 0.318 t ha^{-1}. Accession 9839/25 combined 6.797 t ha^{-1} with 72.83% root-length retention in the collection sucrose assay. Salt-assay responses identified different trait leaders. In the advanced panel, Qorabog retained 92.91% of germination, 94.74% of root number, 53.08% of root length and 75.00% of coleoptile length. New variety 25 retained more root and coleoptile elongation (90.18% and 86.78%) but fewer roots (70.55%). Qorabog exceeded Zamin-1 for all four retention traits in each of the three years. A descriptive four-trait dominance analysis retained Qorabog and New variety 25 as non-dominated candidates. These results support complementary selection of yield-performing accessions and contrasting seedling-response profiles. They establish priorities for subsequent breeding evaluation rather than demonstrating reduced irrigation demand or field drought tolerance.

Keywords: Triticum aestivum; winter wheat; Qorabog; germplasm screening; sucrose; salinity; seedling phenotyping; grain yield

Introduction

Winter wheat improvement in Uzbekistan must address productive performance under irrigation while maintaining useful genetic variation for establishment when water availability is restricted. Imported germplasm and locally developed breeding lines provide different sources of variation. Their value depends on identifying specific traits and testing those traits at the stages and in the environments for which selection is intended. Research with IWWYT-IR material in the Jizzakh region has already demonstrated the importance of evaluating winter wheat across contrasting seasons, particularly for developmental timing [1]. Laboratory screening can complement such field evaluation, but the biological meaning of each assay needs to remain explicit.

Seed germination, production of primary roots, root elongation and coleoptile elongation describe different components of establishment. An entry can produce nearly the same number of roots in a treatment as in its control while showing pronounced inhibition of root elongation. Conversely, a short-rooted genotype can retain a large proportion of its control length without producing the longest roots under treatment. Root-based selection therefore benefits from simultaneous consideration of absolute performance and proportional response. Wasson et al. [2] emphasised the need to connect seedling screens to mature root function and field performance rather than assuming that one necessarily predicts the other.

Controlled osmotic assays also depend on the agent used. Darko et al. [3] showed that different osmolytes can elicit distinct wheat responses even at comparable osmotic potentials. Sucrose exposure, salt exposure and soil drying consequently provide related but non-equivalent forms of evidence. Recent wheat studies have used multiple traits and treatment levels to resolve variation in seedling responses [4,5]. Such work supports joint phenotyping, while also showing why a single retained percentage cannot by itself establish agronomic drought resistance.

The present study brings together collection screening and advanced-material phenotyping within one breeding programme. A preliminary conference account described the advanced-material seedling responses [6]. Here, the analysis is extended by including the 2025 accession yield dataset, the separate collection assays, a four-trait comparison of genotypes with complete data, annual response profiles and an explicit comparison of absolute and relative growth. The objectives were to identify accessions with a yield advantage over the check, distinguish trait-specific responses in the laboratory datasets, and assess whether Qorabog and other advanced materials offer complementary establishment profiles. The datasets are treated as separate evidence streams; they are not represented as a single balanced field–laboratory experiment.

Materials and methods

Study material and organisation of the evidence

The work was associated with the Research Institute of Rainfed Agriculture at Gallaorol, Uzbekistan. The wider breeding programme included introduced winter wheat accessions and local breeding materials. The present analysis used four defined sets of observations: the 2025 grain-yield panel; the 2025 collection sucrose assay; the 2025 collection NaCl assay; and the 2024–2026 advanced-material sucrose assay. Cohort membership was checked before making comparisons. Qorabog was included in the advanced-material assay, not in the 2025 accession yield panel. Accession 9839/25 was present in the collection sucrose assay but absent from the NaCl assay.

The advanced breeding panel with complete data contained Zamin-1, Gurt, Zarbuloq, Muzbuloq, Qorabog, KP-183/2017, KP-174/2021, AE 7/2020, New variety 24 and New variety 25. KP 47/2024 had three-year data for germination, root number and root length but only 2026 coleoptile data, and was therefore not included in four-trait ranking of genotypes with complete data. Lines evaluated only in 2026 were also excluded from this ranking. Qorabog is recorded under selection identifier AS-2009-7 and was derived by individual selection from material of the Andijon 4 × Kroshka // FA 991 combination. This pedigree identifies the cultivar; no causal genetic effects were inferred from it.

Laboratory observations and response calculations

Seeds were assessed in a water control and a sucrose treatment, with germination expressed as a percentage and primary root number expressed as a mean count per seedling. Root and coleoptile lengths were expressed in centimetres. The advanced-material assay used a 3% sucrose solution in 2024–2026. The collection sucrose and NaCl datasets were retained as separate assays, with their respective water controls. Treatment concentrations were not transferred between experiments.

For each genotype and trait, retention was calculated as $R = 100 \times X_t / X_c$, where X_t and X_c are treatment and control values. For the advanced panel, the pooled descriptive value was the ratio of the three annual means, calculated before rounding. Annual retention was also calculated separately within each year. The ratio of annual means and the average of annual ratios answer slightly different questions; the former was used for the main comparison and the latter was not substituted for it. A value above 100% indicates a treatment mean above the control, not an arithmetic error in itself.

The collection analyses used the reported aggregate control and treatment measurements. Germination in a treatment was kept distinct from retention of germination: for example, 90% treatment germination after 98% control germination corresponds to 91.84% retention. Root number and elongation were likewise calculated separately. There was no common treatment-by-genotype statistical model spanning the collection and advanced cohorts.

Yield analysis

The 2025 yield panel comprised 11 entries evaluated in three field repetitions. Yield was converted from centners per hectare to tonnes per hectare by dividing by ten. The one-factor ANOVA had genotype degrees of freedom of 10 and residual degrees of freedom of 22. Its residual mean square was 3.52606 (centners $ha^{-1})^2$, equivalent to 0.0352606 (t $ha^{-1})^2$. Following the significant omnibus test, pairwise differences from Zamin-1 were compared using Fisher's protected least significant difference (LSD) at a two-sided significance level of 0.05.

The LSD was calculated as $t_{0.975,22} \times \sqrt{(2 \times MSE / 3)}$, giving 0.31797 t ha^{-1}. The residual root mean square error, 0.18778 t ha^{-1}, was not treated as an LSD. Within-entry standard deviations and coefficients of variation describe dispersion between field repetitions in this trial. They do not estimate multi-environment stability. Because the layout information available here does not establish a block model, the reported one-factor analysis is retained without presenting it as a randomised complete-block analysis.

Descriptive multi-trait prioritisation

Laboratory measurements were available as annual or treatment aggregates without the underlying experimental-unit data. Consequently, no laboratory standard errors, significance letters, heritabilities or genotype-by-year significance tests were calculated. Years were not substituted for within-year experimental repetitions. Descriptive ranges across years were used to show consistency of direction, rather than to estimate experimental precision.

A non-dominance comparison was applied to the four pooled retention traits of the ten genotypes with complete data. Genotype A dominated B only if A was at least as high as B for all four traits and strictly higher for at least one. All traits were considered desirable in the increasing direction for this screening exercise. No composite index or arbitrary trait weights were introduced. This

calculation is a deterministic summary of the measured profiles and does not establish statistical separation or the biological optimum number of roots. Absolute treatment lengths were considered alongside the retention-based ranking.

Results

Grain yield distinguished six accessions from the check

Mean grain yield ranged from 5.237 t ha^{-1} in Bezostaya-1 to 6.797 t ha^{-1} in 9839/25; the overall mean was 6.462 t ha^{-1}. Zamin-1 yielded 6.247 t ha^{-1}. The one-factor ANOVA indicated differences among entries ($F_{10,22} = 16.417$; $p < 0.0001$), with $R^2 = 0.88183$ and a residual CV of 2.91%. These values quantify fit and residual dispersion within the stated model; R^2 is not interpreted as heritability.

Table 1. Grain yield and within-trial dispersion in the 2025 field panel.

Entry	Yield (t ha^{-1})	SD (t ha^{-1})	CV (%)	Difference from Zamin-1 (t ha^{-1})
Zamin-1	6.247	0.136	2.18	—
Bezostaya-1	5.237	0.153	2.92	-1.010*
9806/25	6.717	0.222	3.30	+0.470*
9807/25	6.647	0.202	3.04	+0.400*
9814/25	6.607	0.153	2.31	+0.360*
9811/25	6.657	0.031	0.46	+0.410*
9819/25	6.487	0.232	3.57	+0.240
9826/25	6.533	0.337	5.15	+0.287
9828/25	6.377	0.192	3.01	+0.130
9833/25	6.777	0.067	0.98	+0.530*
9839/25	6.797	0.153	2.25	+0.550*

Three field repetitions per entry. SD: standard deviation; CV: coefficient of variation. * Absolute difference exceeds protected Fisher $LSD_{0.05} = 0.318$ t ha^{-1}. Stars identify differences in either direction. Error bars in Figure 1 are SD, not confidence intervals.

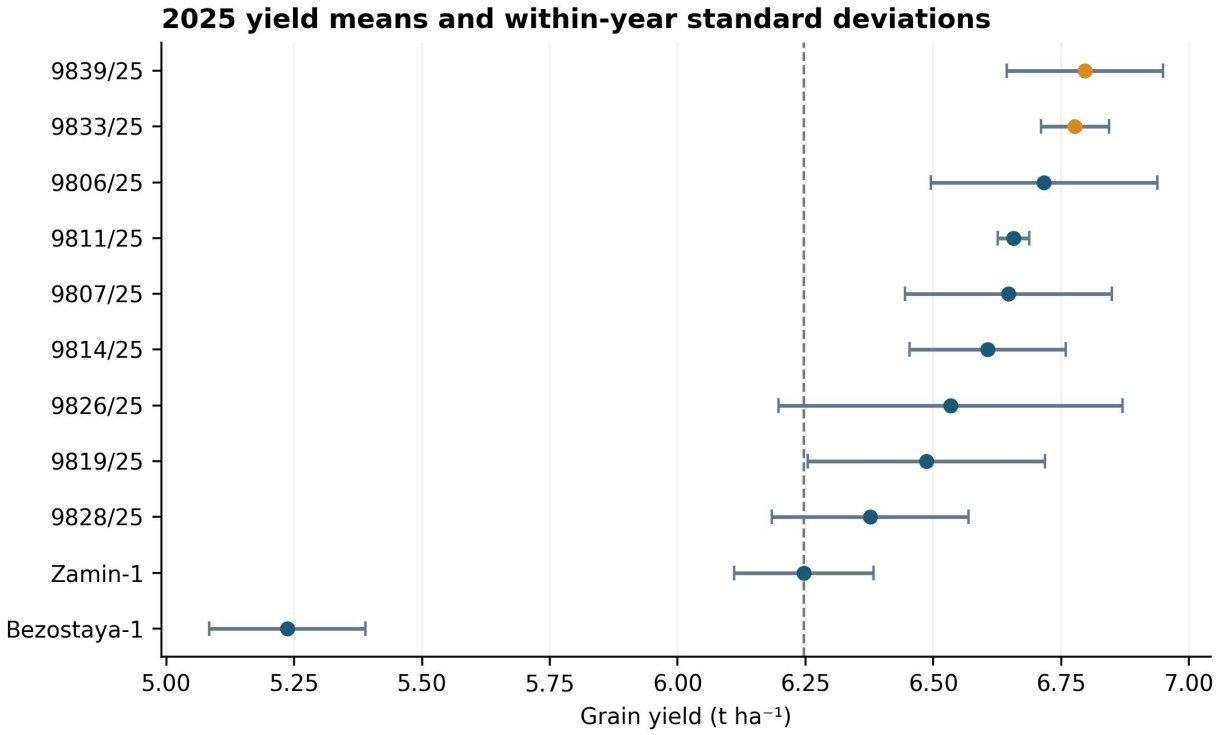


Figure 1. Mean grain yield ± one within-trial SD in the 2025 accession panel (three repetitions). The dashed line marks the Zamin-1 mean. Orange markers identify the two highest mean yields.

Six accessions exceeded Zamin-1 by more than the 0.318 t ha^{-1} LSD: 9806/25, 9807/25, 9814/25, 9811/25, 9833/25 and 9839/25. Their advantages ranged from 0.360 to 0.550 t ha^{-1}. The gains in 9819/25, 9826/25 and 9828/25 were 0.240, 0.287 and 0.130 t ha^{-1}, respectively, and did not exceed this criterion. Accession 9811/25 had a standard deviation of 0.031 t ha^{-1} and a within-trial CV of 0.46%, whereas 9826/25 had a CV of 5.15%. This contrast identifies differences in repetition-level dispersion without establishing performance across sites or seasons.

Collection assays separated germination from elongation responses

In the sucrose assay, germination was 76–90%. Accessions 9807/25 and 9839/25 reached 90%, compared with 76% in Zamin-1. Their germination-retention values were both 91.84%, versus 77.55% in the check. Accession 9839/25 retained its root number at 100%, with a mean of 3.70 roots in each variant. Its root length declined from 9.20 to 6.70 cm, corresponding to 72.83% retention, and its coleoptile declined from 4.11 to 3.42 cm, corresponding to 83.21%. Zamin-1 retained 37.44% of root length and 69.70% of coleoptile length.

Root-length retention was highest in 9839/25, but absolute treatment root length was highest in 9807/25 at 7.03 cm. Accession 9807/25 had a longer control root (10.83 cm), resulting in 64.91% retention. This ordering shows why proportional retention and the size of the organ in the treatment should be interpreted together. The yield advantage of 9839/25 therefore coincided with a favourable collection sucrose profile; it was not tested as a causal consequence of that profile.

Table 2. Germination and elongation retention in the separate 2025 collection assays.

Entry	Sucrose G (%)	Sucrose RL retention (%)	Sucrose CL retention (%)	NaCl G (%)	NaCl RL retention (%)	NaCl CL retention (%)
Zamin-1	76	37.44	69.70	92	30.51	91.43
Bezostaya-1	85	46.58	83.05	98	34.23	72.22
9807/25	90	64.91	76.74	100	50.98	94.59
9808/25	84	44.40	73.37	99	51.35	95.24
9810/25	89	50.58	77.31	96	42.70	36.96
9814/25	85	55.90	82.63	98	52.34	97.30
9816/25	87	43.63	77.67	98	56.41	63.64
9827/25	87	43.00	61.76	97	72.37	89.47
9828/25	86	36.87	77.92	96	41.23	94.12
9832/25	89	35.70	66.87	97	44.79	90.00
9839/25	90	72.83	83.21	—	—	—

G is absolute treatment germination; RL, root length; CL, coleoptile length. Retention uses the matching assay-specific water control. —: not evaluated. Qorabog was not included in these collection panels. Control and treatment means are provided in Supplementary Tables S3 and S4.

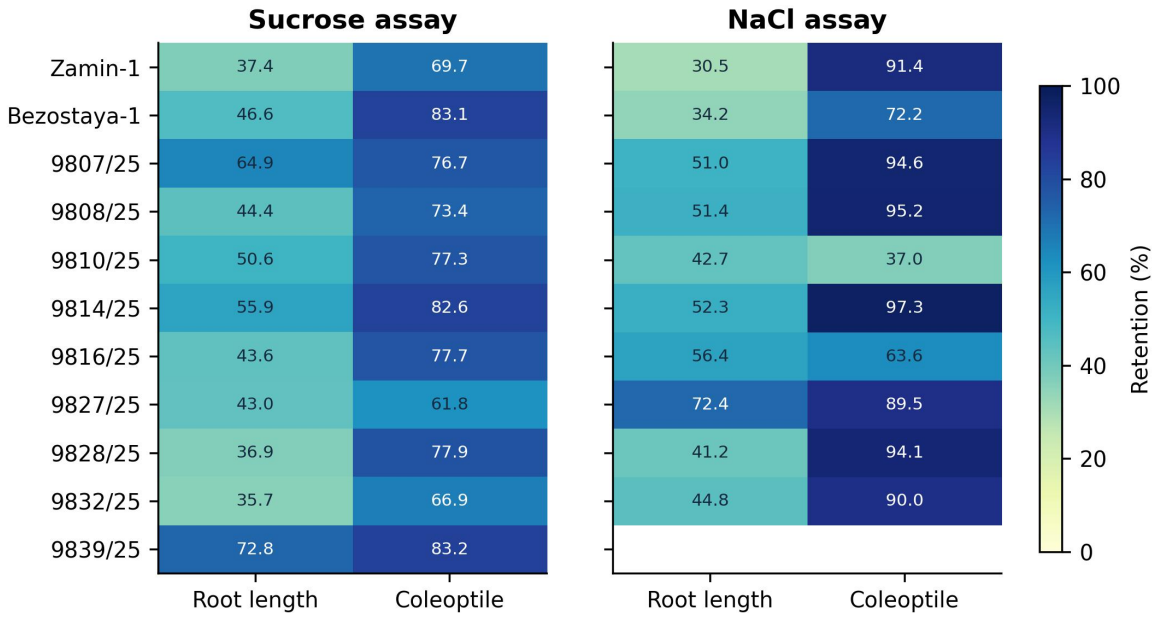


Figure 2. Root and coleoptile length retention in the independent collection sucrose and NaCl assays. Cell values are percentages of the matching water control. The blank final NaCl row reflects the absence of 9839/25 from that assay.

In the NaCl assay, germination ranged from 92% in Zamin-1 to 100% in 9807/25. Root-length retention was highest in 9827/25 at 72.37%, compared with 30.51% in Zamin-1. Coleoptile retention was highest in 9814/25 at 97.30%, followed by 9808/25 at 95.24%. The check retained 91.43%. Root number increased from 3.90 to 4.60 in 9807/25, corresponding to 117.95% retention. This increase was not used as evidence that salt improved overall seedling performance: root length in the same entry declined from 10.20 to 5.20 cm. Accession 9839/25 cannot be assigned a NaCl response because it was not included in that assay.

Advanced materials showed complementary four-trait profiles

In the complete advanced panel, pooled retention ranged from 64.45 to 93.52% for germination, 48.32 to 94.74% for root number, 17.49 to 90.18% for root length, and 27.53 to 86.78% for coleoptile length. Trait leaders were therefore not identical. New variety 25 had the highest germination, root-length and coleoptile retention, whereas Qorabog had the highest root-number retention.

Table 3. Four-trait retention profiles in the ten complete-case advanced materials, 2024–2026.

Genotype	Germination (%)	Root number (%)	Root length (%)	Coleoptile (%)
Zamin-1	64.45	62.68	30.16	32.69
Gurt	69.89	48.32	17.67	33.71
Zarbuloq	77.24	62.33	23.71	42.11
Muzbuloq	89.01	91.15	17.49	27.53
Qorabog	92.91	94.74	53.08	75.00
KP-183/2017	89.53	94.29	36.42	61.45
KP-174/2021	88.40	63.64	36.73	29.81
AE 7/2020	91.81	94.02	43.28	64.71
New variety 24	88.07	89.01	29.37	45.62
New variety 25	93.52	70.55	90.18	86.78

Each value is 100 × the three-year treatment mean divided by the matching control mean, calculated before rounding. These percentages are descriptive response measures; no laboratory significance test is implied. Annual values and absolute means are provided in Supplementary Tables S1 and S2.

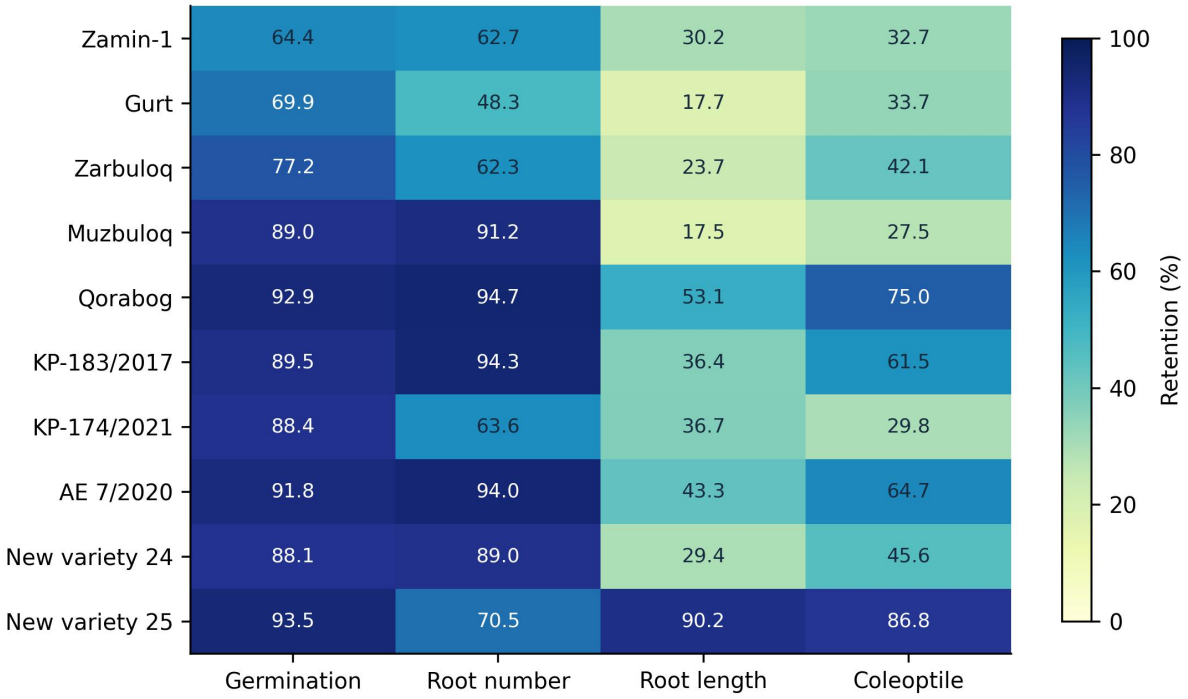


Figure 3. Three-year retention profiles for the ten advanced materials with complete data for all four traits. Higher percentages indicate less proportional reduction; absolute control baselines differ among genotypes.

Qorabog retained 92.91% of germination, 94.74% of root number, 53.08% of root length and 75.00% of coleoptile length. Relative to Zamin-1, the differences were 28.46, 32.06, 22.92 and 42.31 percentage points. Its mean treatment values were 91.67% germination, 4.80 roots, 3.73 cm root length and 3.40 cm coleoptile length. Among the ten common genotypes, Qorabog had the largest mean root number and root length in sucrose, while KP-183/2017 had the longest treatment coleoptile at 3.67 cm.

New variety 25 had 93.52% germination retention, 90.18% root-length retention and 86.78% coleoptile retention, but root-number retention was 70.55%. Its control root length was 3.73 cm and its treatment root length was 3.37 cm. Qorabog had a lower relative root-length retention but a longer root in the treatment (3.73 cm). The difference is attributable to the denominator as well as treatment performance: the Qorabog control root was 7.03 cm. AE 7/2020 retained 91.81% of germination, 94.02% of root number, 43.28% of root length and 64.71% of coleoptile length, placing it above the check on all four pooled measures.

Annual profiles showed a consistent advantage over the check

Qorabog exceeded Zamin-1 for all four retention traits in each year from 2024 to 2026. Annual germination retention in Qorabog ranged from 92.00 to 94.00%, root-number retention from 94.23 to 95.65%, root-length retention from 43.66 to 60.53%, and coleoptile retention from 63.27 to 81.82%. The narrow root-number range contrasted with the broader elongation ranges. Thus, a consistent advantage over the check did not imply identical sensitivity of every trait across years.

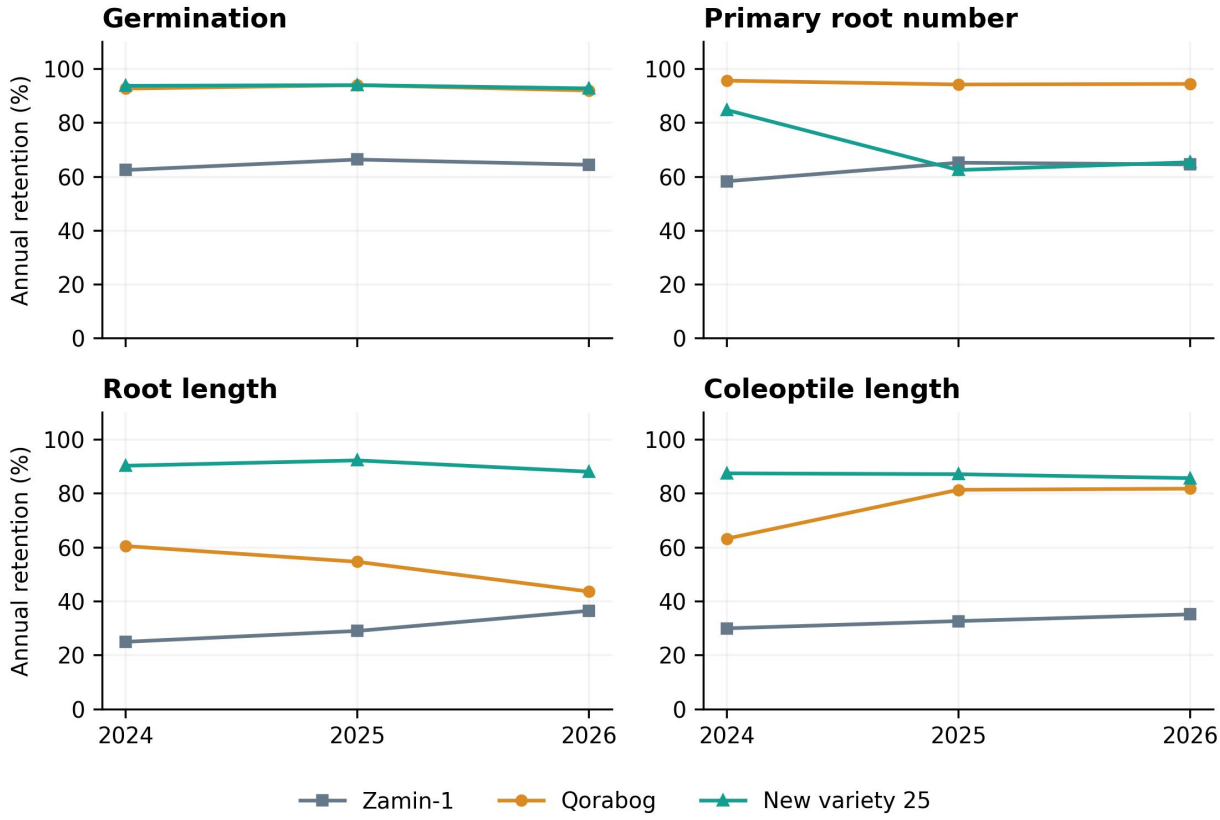


Figure 4. Annual retention in Zamin-1, Qorabog and New variety 25 during 2024–2026. Lines connect annual aggregate observations and are not fitted trends. No error bars are shown because experimental-unit observations were unavailable.

New variety 25 maintained 88.10–92.31% root-length retention and 85.71–87.50% coleoptile retention, whereas root-number retention ranged from 62.50 to 84.78%. These annual profiles reinforce the contrast between root initiation and elongation. The non-dominance calculation on pooled four-trait retention identified Qorabog and New variety 25 as the two non-dominated entries. Qorabog dominated the remaining eight genotypes under the stated arithmetic criterion; neither Qorabog nor New variety 25 dominated the other. This result is specific to the selected traits, the increasing preference direction and the ten-entry panel.

Discussion

Physiological screening and yield evidence support different selection decisions

The evidence identifies useful material at two stages of the programme. The field panel supports accession-level decisions about grain yield under the tested 2025 conditions. The advanced-material panel characterises different seedling response profiles under sucrose exposure. These are complementary selection questions. Because Qorabog was not part of the reported 2025 accession yield panel, its laboratory response cannot be linked statistically to that panel's yield ranking. Conversely, accession 9839/25 should not be treated as a code for Qorabog: they are distinct breeding materials.

Within the collection, 9839/25 combined the largest mean yield with the highest relative root-length retention in sucrose. Accessions 9807/25 and 9814/25 also exceeded the yield check and expressed favourable laboratory traits, although the trait and treatment responsible differed. These results justify prioritising the materials for further experiments. They do not establish a general correlation between laboratory retention and yield across wheat germplasm, because cohort coverage is incomplete and the field trial did not provide a paired water-deficit treatment. This distinction follows the translational approach of linking physiological hypotheses to targeted yield validation [7].

Root initiation and elongation should remain separate phenotypes

The advanced materials illustrate why a single label of "root-system tolerance" can conceal important variation. Muzbuloq retained 91.15% of root number but only 17.49% of root length. Qorabog retained both traits more strongly relative to the check, but the extent of retention was still markedly different between root number and root length. Root initiation, elongation, branching and total root system deployment are distinct developmental processes. Evidence from detailed wheat root phenotyping likewise treats several root dimensions separately rather than substituting one for another [5].

A high count of short roots is not necessarily equivalent to a low count of long roots in soil exploration or water uptake. The present measurements do not resolve rooting depth, branching density, root diameter or hydraulic function. The comparison is therefore most useful for selecting contrasting material for subsequent phenotyping. Qorabog and New variety 25 provide such a contrast: the former maintains root number and a relatively long treatment root, while the latter exhibits strong proportional elongation retention from a shorter control baseline. Crosses or physiological comparisons between these materials would require additional information on pedigree relatedness, flowering behaviour and agronomic compatibility before a breeding decision.

Absolute performance prevents overinterpretation of ratio rankings

The root-length comparison between Qorabog and New variety 25 is a direct example of denominator dependence. Selecting only the largest retention percentage would favour New variety 25, yet selecting the longest treatment root would favour Qorabog. In the collection assay, the same issue separates 9839/25 and 9807/25. Neither criterion is universally sufficient. A ratio answers how much of the genotype's own control value is retained; the treatment value answers how much growth is achieved under that assay. A transparent screen should report both.

The non-dominance analysis retains this trait structure without imposing a weighted "tolerance score". It reveals complementary candidates rather than forcing one winner. Nevertheless, non-dominance is not a significance test, and the result can change if measurement uncertainty, additional traits or alternative breeding objectives are introduced. The absence of laboratory experimental-unit observations precludes resampling-based confidence estimates. The resulting two-entry set should therefore be interpreted as a reproducible descriptive shortlist, not as proof that all other materials lack breeding value.

Treatment chemistry and developmental stage limit agronomic extrapolation

The 3% sucrose treatment is an early-growth assay, not a direct measurement of irrigation demand. Sucrose can affect carbon supply and signalling as well as solution osmotic conditions, so a cultivar response cannot be attributed to water deficit alone without appropriate controls. Darko et al. [3] demonstrate why osmolyte identity matters. Recent multi-gradient PEG work provides a useful experimental contrast [4], but its dose–response results cannot calibrate the unmeasured water potential of the present sucrose solution. The NaCl assay also includes ion-specific effects that are absent from a non-ionic treatment.

The recurring differences across three years strengthen confidence that the reported profile is not confined to a single annual aggregate. They do not establish field stability, because the assay conditions, seed-lot properties and within-year variability require documentation. Controlled seedling phenotypes should be tested against establishment, canopy development and yield under defined field water regimes. As outlined by Wasson et al. [2], a convincing root-selection programme requires validation of the connection between the selected early trait and mature field function. The present analysis supplies candidates and contrasts for that step.

Breeding implications and limits of the available evidence

Three practical priorities emerge. First, retain the six yield-performing accessions for field evaluation across additional seasons or locations, using suitable plot-level models. Second, compare Qorabog and New variety 25 under standardised treatment gradients while measuring absolute and relative root and coleoptile growth. Third, carry forward accession 9839/25 for combined yield and sucrose-response evaluation without assigning it an unmeasured salt response. AE 7/2020 and KP-183/2017 remain useful comparators for root-number or coleoptile traits even though their four-trait retention profiles were dominated in this particular screen.

The analysis has limitations that define its interpretation. The field result comes from one year and the laboratory results are aggregates. Laboratory precision and seedling treatment-by-genotype inference cannot be reconstructed without experimental-unit data. Collection treatment concentrations, timing and environmental conditions need to be tied to the original protocol. One-year lines requiring verification were excluded from the multi-trait ranking, and no missing observations were imputed. Disease resistance, salinity tolerance of Qorabog, genetic mechanisms and water savings are outside the evidence tested here. These boundaries keep the selection recommendations proportional to the observations.

Conclusions

The 2025 field trial identified six winter wheat accessions with a yield advantage over Zamin-1 under the reported one-factor analysis. Accession 9839/25 combined 6.797 t ha^{-1} with high root-length retention in the separate collection sucrose assay. Laboratory responses were trait- and treatment-specific: high germination or root number did not necessarily imply strong elongation retention. In the ten-entry three-year advanced panel, Qorabog consistently exceeded the check across four retention traits, while New variety 25 combined strong elongation retention with lower root-number retention. Their non-dominated profiles justify complementary further evaluation. The results support targeted breeding decisions and the design of field validation, without establishing reduced irrigation requirement or a general laboratory predictor of drought yield.

Data availability

The grain-yield statistics, germination measurements and early seedling growth data analysed in this study are presented in Tables 1–3 and Supplementary Tables S1–S4.

Prior dissemination

A preliminary account of the advanced-material seedling study appeared in conference proceedings [6]. The present manuscript adds a separate field-yield dataset, collection-assay comparisons, complete-case multi-trait prioritisation and annual response analysis. The proceedings report is cited to identify the overlap in the advanced-material observations.

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