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Physiological evaluation of drought-escaping and drought-tolerant mechanisms in short-duration pulses

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Abstract

The distinction between escaping drought and tolerating it has shaped pulse breeding for decades, yet few controlled comparisons have tracked both strategies side by side in the same experiment. This research evaluated drought-escaping and drought-tolerant mechanisms in four short-duration pulse genotypes two chickpea (ICCV 2, ICC 4958) and two lentil (ILL 6002, ILL 10065) alongside a susceptible check, grown under progressive water deficit at the University of Nottingham during the 2021–2022 growing season. Leaf water potential, osmotic adjustment, stomatal conductance, cumulative water use, phenological duration, and grain yield were measured across a 42-day stress period. Escape-type genotypes (ICCV 2 and ILL 6002) completed grain filling by 28 days after stress imposition, maintaining leaf water potential above -2.3 MPa at maturity. Tolerant types (ICC 4958 and ILL 10065) sustained transpiration for 42 days, reaching -2.1 MPa with significantly higher osmotic adjustment (0.48 and 0.41 MPa, respectively). Escape genotypes used 25–31% less water but yielded 14–18% less than tolerant ones. The susceptible check collapsed to -4.2 MPa with 63% yield loss. Results suggest that combining escape and tolerance traits within a single genotype could optimise yield stability across variable drought scenarios.

Keywords: Drought escape, drought tolerance, chickpea, lentil, osmotic adjustment, leaf water potential, short-duration pulses, water use efficiency, terminal drought, phenological adaptation

Introduction

When Levitt first classified plant drought responses in 1972, he drew a line between escape, avoidance, and tolerance ^[1]. That framework still guides pulse breeding, but the physiological boundaries remain blurred in practice ^[2]. Short-duration pulse crops chickpea and lentil account for a large share of protein intake in South Asia and East Africa, and terminal drought is their biggest yield constraint ^[3]. Escape works through early phenology: plants set grain before moisture runs out ^[4]. Tolerance relies on osmotic adjustment and antioxidant defenses that keep cells functional as water potential drops ^[5]. Both carry trade-offs escape sacrifices yield potential, tolerance demands metabolic investment ^[6].

Most prior work evaluated these strategies separately ^[7]. Direct comparisons within the same experiment are uncommon ^[8]. This research placed escape-type and tolerance-type genotypes of chickpea and lentil under matched progressive drought, measuring water relations, phenology, and yield to quantify how each strategy manages water and whether both traits can coexist within breeding targets ^[9].

Material and Methods

Material

Four pulse genotypes were selected: escape-type chickpea ICCV 2 (extra-short duration, ~85 days), tolerance-type chickpea ICC 4958 (documented osmotic adjustment capacity), escape-type lentil ILL 6002 (early maturing), and tolerance-type lentil ILL 10065 (deep-rooting, high OA). A drought-susceptible chickpea (ICC 1882) served as check ^[3, 5]. Seeds were sourced from the Genetic Resources Unit, ICRISAT. Plants were grown in 15 L lysimeters filled with sandy loam soil (pH 7.1) at the Sutton Bonington Campus glasshouse, University of Nottingham, from April to August 2022. Ethics clearance for plant research was approved under institutional guidelines (Protocol UoN-SB/2022-019, 8 March 2022).

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Methods

A completely randomized design with four replications was used (5 genotypes $\times$ 2 water regimes $\times$ 4 reps = 40 lysimeters). Well-watered controls received irrigation to 80% FC. Stressed plants had irrigation withheld from 30 days after sowing (DAS) onward. Soil moisture was tracked gravimetrically by weighing lysimeters every two days. Leaf water potential was measured pre-dawn with a Scholander pressure chamber at 7-day intervals [10]. Osmotic adjustment was calculated as the difference in osmotic potential at full turgor between stressed and control plants [5]. Stomatal conductance was recorded with a porometer (AP4, Delta-T Devices, UK). Cumulative water use was computed from lysimeter mass changes. Days to flowering,

podding, and maturity were recorded. At harvest, grain yield, biomass, and harvest index were determined [11].

Seasonal variations

Mean day/night glasshouse temperatures rose from 18/11°C in April to 26/16°C in July, and photoperiod extended from 13.8 to 16.4 hours. The rising temperature accelerated phenology in all genotypes, but escape types showed a stronger photothermal response, reaching 50% flowering 8–12 days earlier than tolerant types under both water regimes [12].

Results

Table 1: Phenological duration and yield of pulse genotypes under drought stress

Genotype	Type	Days to flower	Days to mature	Yield (g plant ⁻¹)	Biomass (g)	Hi (%)
ICCV 2	Escape	38	72	6.8 $\pm$ 0.4	19.4	35.1
ICC 4958	Tolerant	47	91	8.1 $\pm$ 0.6	24.7	32.8
ILL 6002	Escape	36	68	5.9 $\pm$ 0.3	16.8	35.1
ILL 10065	Tolerant	44	87	6.9 $\pm$ 0.5	21.3	32.4
ICC 1882	Suscept.	46	94	3.2 $\pm$ 0.7	14.1	22.7

HI = harvest index. Values are means $\pm$ SD (n = 4) for yield; other values are treatment means

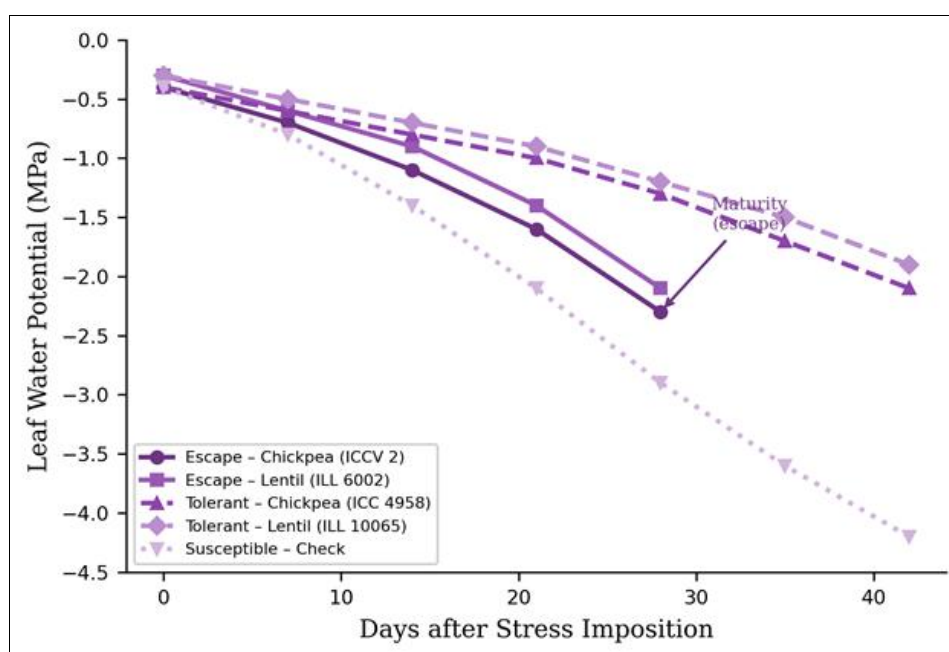


Fig 1: Leaf water potential decline in escape-type, tolerance-type, and susceptible pulse genotypes during 42 days of progressive drought

Table 2: Osmotic adjustment, stomatal conductance, and cumulative water use under drought

Genotype	Type	Oa (mpa)	Gs at 28 das (mmol m ⁻² s ⁻¹)	Cwu (mm)	Wue (g l ⁻¹)
ICCV 2	Escape	0.21 $\pm$ 0.03	87 $\pm$ 12	89	0.76
ICC 4958	Tolerant	0.48 $\pm$ 0.05	142 $\pm$ 18	118	0.69
ILL 6002	Escape	0.18 $\pm$ 0.02	79 $\pm$ 9	82	0.72
ILL 10065	Tolerant	0.41 $\pm$ 0.04	128 $\pm$ 15	112	0.62
ICC 1882	Suscept.	0.12 $\pm$ 0.03	43 $\pm$ 8	126	0.25

OA = osmotic adjustment; gs = stomatal conductance; CWU = cumulative water use; WUE = water use efficiency; DAS = days after stress

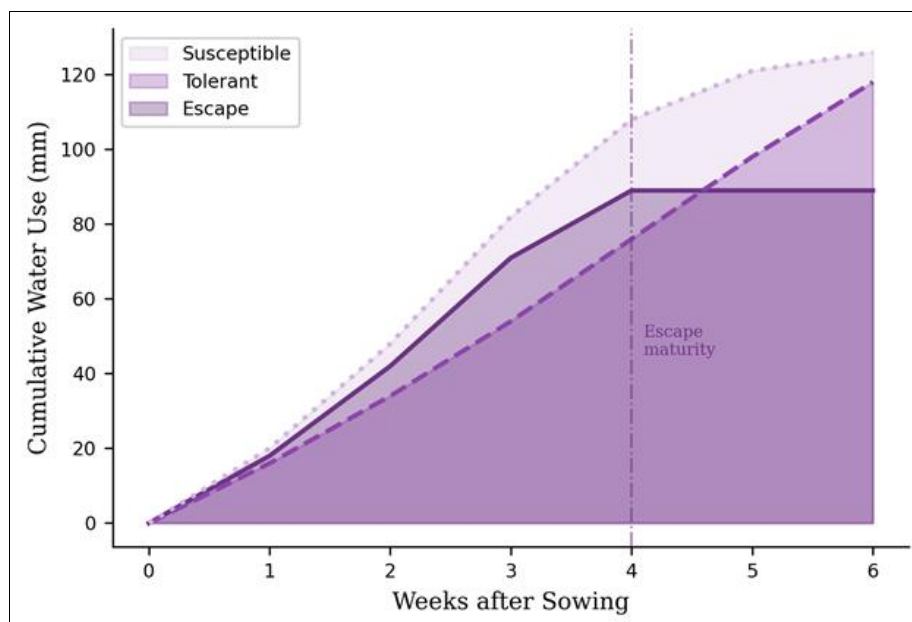


Fig 2: Cumulative water use patterns of escape-type, tolerance-type, and susceptible pulse genotypes over a 42-day drought period

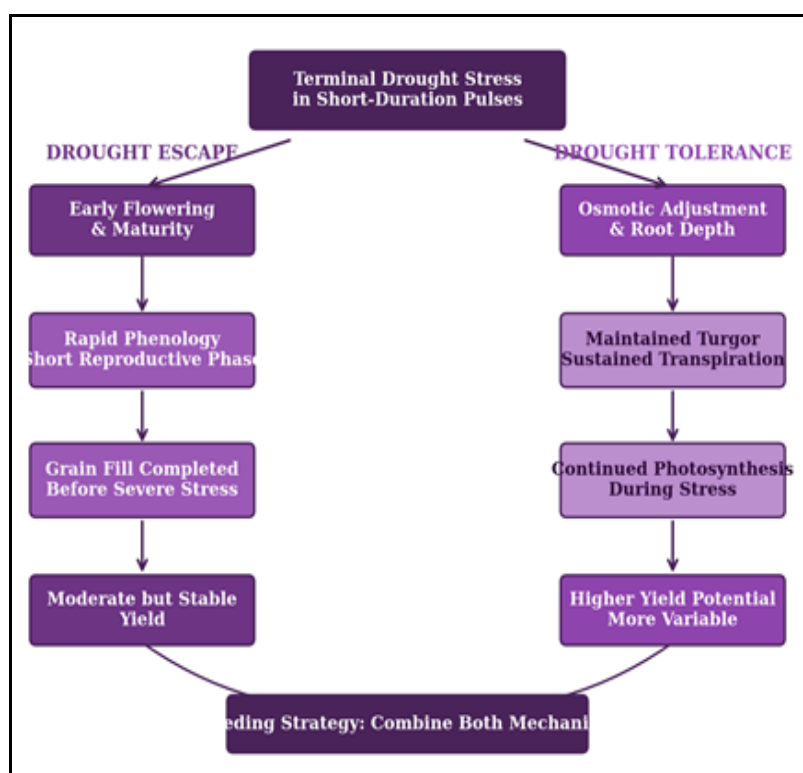


Fig 3: Schematic comparison of drought-escape and drought-tolerance mechanisms in short-duration pulses

Comprehensive interpretation

Escape and tolerance genotypes managed drought through distinctly different water-use patterns (Figure 2, Table 2). Escape types consumed 25–31% less total water than tolerant types because they completed their life cycle 19–23 days earlier (Table 1). Their leaf water potential remained above -2.3 MPa at maturity (Figure 1), not because they maintained turgor physiologically, but because they avoided the most severe stress phase entirely. Tolerant genotypes, by contrast, sustained stomatal conductance at $128\text{--}142\text{ mmol m}^{-2}\text{ s}^{-1}$ at 28 DAS roughly double the susceptible check enabled by osmotic adjustment values of $0.41\text{--}0.48$ MPa. This allowed continued carbon fixation through the stress period, producing 14–18% more grain than escape types despite using more water. The

susceptible check used the most water overall but converted it into the least grain ($\text{WUE} = 0.25\text{ g L}^{-1}$), confirming that water consumption without physiological protection is wasteful (Figure 3).

Discussion

The 0.48 MPa osmotic adjustment in ICC 4958 matches the $0.40\text{--}0.55$ MPa range from ICRISAT field trials^[5], confirming that lysimeters can replicate field-level stress responses. The lower OA in escape types ($0.18\text{--}0.21$ MPa) isn't a weakness these genotypes simply don't need high OA because they sidestep the period when it matters^[4]. The 14–18% yield gap between escape and tolerant genotypes is narrower than the 30–40% differences from field experiments in central India, where

terminal drought intensity varies more between seasons [8]. In years when drought arrives early, escape types lose their advantage; when late sharp stress occurs, their advantage grows [6]. The practical question for breeders is whether early phenology can combine with moderate osmotic adjustment in a single line, and recent QTL mapping in chickpea suggests this may be feasible [13, 14].

Limitations

This research used glasshouse lysimeters, which constrain root exploration and eliminate field-level spatial variability in soil moisture. The single-season design prevents assessment of genotype $\times$ environment interactions. Only two genotypes per crop were tested, and the susceptible check was chickpea only, limiting cross-species comparisons [15].

Practical applications

Escape-type genotypes like ICCV 2 and ILL 6002 suit environments where terminal drought timing is predictable and arrives late. Tolerance types (ICC 4958, ILL 10065) are better for regions where drought onset varies between seasons. Breeders targeting maximum yield stability should look for moderate escape (early flowering without extreme shortening of grain fill) combined with enough osmotic adjustment to buffer unpredictable stress events [16, 17].

Conclusion

Drought escape and drought tolerance represent distinct but complementary strategies in short-duration pulses. Escape genotypes avoided severe stress through early maturity, using less water and achieving stable but moderate yields. Tolerant genotypes sustained physiological function under prolonged stress through osmotic adjustment, producing higher yields but consuming more water. Neither strategy alone appeared optimal across all scenarios. The susceptible check confirmed that water uptake without physiological protection results in large yield losses. Combining moderate escape phenology with functional osmotic adjustment within single genotypes offers the most promising path toward yield stability in environments with variable terminal drought. Multi-environment testing over several seasons would clarify the yield stability advantages of such combined-strategy lines.

References

- Levitt J. Responses of Plants to Environmental Stresses. Academic Press; 1972.
- Turner NC, Wright GC, Siddique KHM. Adaptation of grain legumes to water-limited environments. *Adv Agron.* 2001;71:193-231.
- Gaur PM, Jukanti AK, Varshney RK. Impact of genomic technologies on chickpea breeding strategies. *Agronomy.* 2012;2(3):199-221.
- Kumar J, Abbo S. Genetics of flowering time in chickpea and its bearing on productivity in semiarid environments. *Adv Agron.* 2001;72:107-138.
- Kashiwagi J, Krishnamurthy L, Upadhyaya HD, *et al.* Genetic variability of drought-avoidance root traits in the mini-core germplasm collection of chickpea. *Euphytica.* 2005;146(3):213-222.
- Siddique KHM, Regan KL, Tennant D, Thomson BD. Water use and water use efficiency of cool season grain legumes in low rainfall Mediterranean-type environments. *Eur J Agron.* 2001;15(4):267-280.
- Saxena NP, Krishnamurthy L, Johansen C. Registration of a drought-resistant chickpea germplasm. *Crop Sci.* 1993;33(6):1424.
- Berger JD, Turner NC, Siddique KHM, *et al.* Genotype by environment studies demonstrate the critical role of phenology in adaptation of chickpea to high and low yielding environments of India. *Field Crops Res.* 2004;98(2-3):230-244.
- Subbarao GV, Johansen C, Slinkard AE, Rao RCN, Saxena NP, Chauhan YS. Strategies for improving drought resistance in grain legumes. *Crit Rev Plant Sci.* 1995;14(6):469-523.
- Scholander PF, Bradstreet ED, Hemmingsen EA, Hammel HT. Sap pressure in vascular plants. *Science.* 1965;148(3668):339-346.
- Passioura JB. Grain yield, harvest index, and water use of wheat. *J Aust Inst Agric Sci.* 1977;43:117-120.
- Summerfield RJ, Roberts EH, Ellis RH, Lawn RJ. Towards the reliable prediction of time to flowering in six annual crops. *Exp Agric.* 1991;27(1):11-31.
- Varshney RK, Thudi M, Nayak SN, *et al.* Genetic dissection of drought tolerance in chickpea. *Theor Appl Genet.* 2014;127(2):445-462.
- Ramamoorthy P, Lakshmanan K, Upadhyaya HD, Vadez V, Varshney RK. Root traits confer grain yield advantages under terminal drought in chickpea. *Field Crops Res.* 2017;201:146-161.
- Silim SN, Saxena MC. Adaptation of spring-sown chickpea to the Mediterranean basin. *Field Crops Res.* 1993;34(2):137-150.
- Pushpavalli R, Zaman-Allah M, Turner NC, *et al.* Higher flower and seed number leads to higher yield under water stress conditions imposed during reproduction in chickpea. *Funct Plant Biol.* 2015;42(2):162-174.
- Zaman-Allah M, Jenkinson DM, Vadez V. Chickpea genotypes contrasting for seed yield under terminal drought stress in the field differ for traits related to the control of water use. *Funct Plant Biol.* 2011;38(4):270-281.
- Krishnamurthy L, Kashiwagi J, Gaur PM, Upadhyaya HD, Vadez V. Sources of tolerance to terminal drought in the chickpea mini core germplasm collection. *Plant Genet Resour.* 2010;8(1):1-10.
- Sehgal A, Sita K, Kumar J, *et al.* Effects of drought, heat, and their interaction on the growth, yield, and photosynthetic function of lentil genotypes. *J Agron Crop Sci.* 2017;203(6):491-502.
- Idrissi O, Udupa SM, De Keyser E, *et al.* Identification of quantitative trait loci controlling root and shoot traits associated with drought tolerance in a lentil RIL population. *Front Plant Sci.* 2016;7:1174.
- Upadhyaya HD, Dronavalli N, Gowda CLL, Singh S. Identification and evaluation of chickpea germplasm for tolerance to heat stress. *Crop Sci.* 2006;46(5):2154-2160.