RESEARCH ARTICLE
Legume Research- An International Journal, Volume 49 Issue 6: 959-966 (June 2026)

# Assessment of Morphological and Biochemical Traits in Vegetable Pea (*Pisum sativum* var. *Hortense* L.) Genotypes for Drought Tolerance in Eastern Sub-Himalayan Agroecology

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10.18805/LR-5615

## ABSTRACT

**Background:** Due to changing climatic conditions, the growing window for peasis decreasing and also affecting the production of vegetable peas. The current study was conducted to evaluate 28 vegetable pea genotypes under normal and drought-stress conditions to identify drought-tolerant lines based on morphological and biochemical traits.

**Methods:** The study involves screening of pea genotypes for different morphological traits, yield, harvest index, seed yield and biochemical traits related to drought resistance in pea. The drought tolerance index (DTI) was used to identify genotypes with steady performance under stress.

**Result:** Under drought stress, the nodules per plant were reduced, flowering was delayed and plant height was reduced. Pods per plant dropped, seeds per pod reduced, while root length increased from 15.3 cm to 18.9 cm under stress, thus suggesting an adaptive response. The analysis revealed that RPCAU-23-5, Kashi Udai, Arka Chaitra and KSP-110 have demonstratedsignificantly higher mean performance values compared to the mean under drought treatments. An increased content of Proline, catalase and peroxidase was observed, indicating involvement in drought tolerance. The result indicated that some genotypes under drought conditions can be utilised for further study and improvement.

**Key words:** Biochemical, Drought, Morphological, Pea, Tolerance, Yield.

## INTRODUCTION

The vegetable pea (*Pisum sativum* var. *hortense* L.) is a globally important legume valued for fresh consumption and processing. As a nutrient dense crop, it provides high-quality plant protein, essential amino acids and key minerals such as calcium, iron, potassium and phosphorus (Dahl *et al*., 2012). Its richness in lysine-often limited in cereal-based diets-makes peas crucial for improving nutritional security and combating global malnutrition (Wu *et al*., 2023). Beyond basic nutrition, peas contain bioactive compounds with antioxidant, anti-inflammatory and anticancer properties, reinforcing their significance as functional foods (Castaldo *et al*., 2021).

Agronomically, peas enhance soil fertility through biological nitrogen fixation, making them integral to sustainable cropping systems. Although they perform best in temperate regions, their productivity is increasingly constrained by abiotic stresses, particularly drought. Drought episodes critically reduce growth, flowering and pod filling, causing substantial yield losses (Karatas *et al*., 2014). Water deficit disrupts water and nutrient uptake, limits photosynthesis and induces stomatal closure (Farooq *et al*., 2009). It also enhances reactive oxygen species (ROS) production, damaging cellular structures. Plants mitigate these effects through antioxidant enzymes such as catalase and peroxidase (Cruz de Carvalho, 2008) and through osmotic adjustment *via* proline and other osmolytes (Renzetti *et al*., 2024 and Kumar *et al*., 2021).

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**How to cite this article:** Singh, S., Kumar, U., Yadav, R.K., Neeraj, Pramila, Dharminder and Kumar, S. (2026). Assessment of Morphological and Biochemical Traits in Vegetable Pea (*Pisum sativum* var. *Hortense* L.) Genotypes for Drought Tolerance in Eastern Sub-Himalayan Agroecology. *Legume Research.* **49(6):** 959-966. doi: 10.18805/LR-5615.

**Submitted:** 01-12-2025 **Accepted:** 14-03-2026 **Online:** 22-04-2026

Pea genotypes display considerable diversity in drought responses, influenced by traits like root architecture, chlorophyll content, relative water content and osmolyte accumulation (Zhang *et al*., 2024). Biochemical parameters, including proline and antioxidant activity, are reliable indicators of stress tolerance (Aina *et al*., 2024).

Drought tolerance indices such as STI, GMP, MP, SSI and TOL (Ayalew *et al*., 2016) further aid in identifying stable, high-performing genotypes. This study integrates morphological, physiological and biochemical assessments with drought indices to identify resilient vegetable pea genotypes suited for water-limited environments.

## MATERIALS AND METHODS

The field experiment was conducted during *Rabi* 2023-24 at the Rain-out Shelter Unit of RPCAU, Pusa, Bihar, under a humid subtropical climate (Table 1). The physical and chemical properties of experimental soil was analysed to know the nutrient status of the experimental unit (Table 2). Twenty-eight vegetable pea genotypes were evaluated under drought and non-drought conditions. Seeds were treated with *Rhizobium leguminosarum* (20 g/kg) using jaggery as an adhesive and sown on 24 November 2023; harvesting began on 5 March 2024. Observations were recorded on five randomly selected plants per plot for morphological, yield, biochemical and drought-tolerance traits. Measured parameters included nodules per plant, phenological traits, plant height, branches, pods per plant, seeds per pod, root length, biological yield, seed yield, pod yield, shelling percentage and harvest index. Proline content, catalase and peroxidase activities were quantified following standard protocols. Drought tolerance was assessed using DTI, DSI with DII and the Tolerance Index. Data were statistically analysed using GRAPES software (Gopinath *et al*., 2020).

## RESULTS AND DISCUSSION

The mean performance of selected genotypes under normal and drought conditions in vegetable pea was evaluated and presented (Table 3.1 and 3.2) under the following heads.

### Performance of genotypes based on morphological traits and yield parameters

#### Number of nodules per plant

Under normal conditions, nodule numbers ranged from 9.57 (Saloni) to 24.93 (Pusa Pragati and Kashi Ageti), averaging 15.22. Kashi Mukti and Kashi Ageti outperformed the check Kashi Nandini. Under drought, values declined to 7.73-19.40, with a mean of 12.60, though Kashi Samridhi and Kashi Ageti remained superior to the check. Overall, nodulation was reduced under drought, aligning with Couchoud *et al*. (2020), who reported a 24-33% decline in nodule biomass.

#### Days to flower initiation

Under normal conditions, days to flower initiation ranged from 39.24 to 59.68, averaging 49.84, with Kashi Mukti and AP-1 flowering earlier than the check Kashi Nandini. Under drought, flowering ranged from 41.96 to 54.09, with a mean of 46.67, showing earlier induction. This advancement aligns with earlier reports indicating drought can accelerate flowering by 2-3 days (Govind *et al*., 2021; Yathish *et al*., 2021).

**Table 1:** Meteorological data during the study period.

| Month | Temperature (°C) | | Relative humidity (%) | | Rainfall |
|---|---|---|---|---|---|
| | Min. | Max. | Min. | Max. | (mm) |
| Nov. 2023 | 16.3 | 29.8 | 53.00 | 95.00 | 0.0 |
| Dec. 2023 | 12.0 | 24.90 | 59.00 | 97.00 | 4.6 |
| Jan. 2024 | 8.9 | 17.6 | 73.00 | 98.00 | 0.0 |
| Feb. 2024 | 11.1 | 24.8 | 56.00 | 95.00 | 6.2 |
| March 2024 | 15.3 | 29.2 | 52.00 | 90.00 | 43.8 |
| April 2024 | 20.4 | 37.6 | 33.00 | 70.00 | 0.0 |

Min.: Maximum; Max.: Maximum; mm: Millimetre.

**Table 2:** Physical and chemical properties of experimental soil.

| Particulars | Value | Method employed |
|---|---|---|
| Textural class | Loamy sand with a whitish-brown colour | Bouyoucos hydrometer |
| pH | 8.1 | Digital pH meter |
| EC ($dSm^{-1}$) | 0.39 | Conductivity bridge |
| Organic carbon (%) | 0.48 | Rapid Titration Method (Walkley and Black, 1934) |
| Available nitrogen (kg/ha) | 192.14 | Modified Macro Kjeldhal Method (Kirk, 1950) |
| Available phosphorus (kg/ha) | 18.30 | Olsen’s method (Olsen, 1954) |
| Available potassium (kg/ha) | 139.67 | Flame photometer method (Pratt, 1965) |

**Table 3.1:** Mean performance of vegetable pea genotypes under normal and drought conditions.

| Characters | DM | | DFI | | PH (cm) | | NNPP | | RL (cm) | | BPP | | PPP | | SPP | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Genotypes | N | D | N | D | N | D | N | D | N | D | N | D | N | D | N | D |
| Kashi samridhi | 61.3 | 54.65 | 45.95 | 42.60 | 60.85 | 63.95 | 21.20 | 18.77 | 26.1 | 27.83 | 18.97 | 15.03 | 15.58 | 12.92 | 7.43 | 6.48 |
| Kashi mukti | 61.95 | 55.78 | 47.23 | 43.95 | 57.13 | 44.59 | 22.57 | 17.53 | 21.04 | 24.33 | 16.4 | 12.23 | 16.82 | 12.42 | 7.83 | 7.26 |
| RPCAU-23-17 | 70.34 | 63.55 | 54.23 | 47.58 | 75.34 | 53.20 | 13.5 | 9.53 | 19.5 | 26.93 | 8.5 | 6.03 | 8.11 | 7.09 | 9.23 | 7.90 |
| DVP-8 | 67.68 | 59.16 | 51.5 | 47.30 | 48.88 | 41.28 | 10.2 | 7.73 | 14.63 | 15.67 | 5.83 | 4.17 | 7.94 | 6.44 | 7.37 | 6.13 |
| RPCAU-23-5 | 64.45 | 60.87 | 48.88 | 48.76 | 56.26 | 49.20 | 13.03 | 10.17 | 16.27 | 18.57 | 7.2 | 5.07 | 8.33 | 7.02 | 7.83 | 6.90 |
| RPCAU-23-9 | 55.28 | 53.61 | 39.24 | 45.90 | 48.43 | 40.06 | 15.27 | 11.57 | 9.62 | 13.63 | 8.43 | 6.00 | 7.98 | 6.35 | 6.93 | 6.15 |
| Pea 18503656 | 75.61 | 69.06 | 59.68 | 54.09 | 51.5 | 48.79 | 10.67 | 10.60 | 12.64 | 15.63 | 7.8 | 5.13 | 6.4 | 6.07 | 7.17 | 6.57 |
| AP-1 | 67.06 | 60.36 | 51.5 | 45.64 | 84.69 | 68.12 | 17.83 | 14.00 | 18.4 | 22.47 | 16.93 | 15.03 | 14.28 | 13.21 | 8.07 | 7.40 |
| Arkel | 63.89 | 56.32 | 45.85 | 42.50 | 80.24 | 71.07 | 13.83 | 11.43 | 18.27 | 21.23 | 17.87 | 15.37 | 6.72 | 6.67 | 6.3 | 6.34 |
| Saloni | 73.37 | 66.49 | 55.97 | 50.04 | 64.78 | 53.27 | 9.57 | 9.40 | 14.9 | 12.67 | 14.03 | 11.13 | 8.74 | 8.40 | 6.57 | 7.04 |
| AP-3 | 62.91 | 58.88 | 47.05 | 45.91 | 74.04 | 63.57 | 16.67 | 13.60 | 19.17 | 20.37 | 13.43 | 13.13 | 15.07 | 13.38 | 6.87 | 6.03 |
| Kashi uday | 61.8 | 59.38 | 43.89 | 45.02 | 66.36 | 53.90 | 13.5 | 11.80 | 17.27 | 19.53 | 12.23 | 8.87 | 9.14 | 7.72 | 5.9 | 6.00 |
| Arka priya | 71.64 | 64.26 | 54.22 | 49.02 | 70.42 | 59.20 | 12.3 | 8.97 | 19.2 | 19.67 | 14.93 | 10.53 | 15.28 | 10.36 | 7.97 | 6.96 |
| Arka uttam | 70.38 | 63.19 | 52.94 | 48.77 | 103.12 | 85.54 | 10.33 | 8.77 | 19.57 | 21.73 | 14.47 | 12.97 | 7.94 | 6.22 | 6.5 | 6.70 |
| VL-3 | 65.38 | 61.37 | 52.05 | 47.75 | 65.66 | 53.55 | 12.1 | 10.57 | 18.67 | 19.97 | 13.9 | 13.27 | 9.19 | 7.33 | 6.57 | 6.66 |
| RPCAU-23-11 | 71.25 | 68.00 | 58.66 | 53.07 | 59.18 | 50.53 | 13.83 | 10.40 | 15.4 | 16.60 | 10.3 | 7.97 | 8.44 | 7.51 | 6.43 | 6.57 |
| RPCAU-23-16 | 57.46 | 60.94 | 40.88 | 42.94 | 74.27 | 63.04 | 9.97 | 9.80 | 12.5 | 16.83 | 8.73 | 7.40 | 7.62 | 6.58 | 5.97 | 5.60 |
| Snow pea | 68.4 | 57.22 | 46.87 | 42.18 | 67.01 | 55.35 | 14.13 | 12.70 | 16.13 | 18.60 | 7.3 | 9.20 | 8.5 | 6.82 | 6.13 | 6.76 |
| NS-1100 | 64.98 | 60.66 | 47.16 | 44.31 | 66.82 | 44.65 | 14.6 | 12.30 | 18.1 | 21.87 | 7.93 | 7.00 | 8.17 | 7.16 | 7.13 | 6.66 |
| KSP-110 | 73.83 | 63.41 | 59.6 | 53.89 | 58.84 | 44.96 | 14.1 | 10.33 | 22.27 | 19.13 | 14.77 | 17.70 | 13.51 | 6.18 | 8.6 | 7.26 |
| Kashi nandini | 66.91 | 61.34 | 50.87 | 46.64 | 70.32 | 57.63 | 19.9 | 17.53 | 20.4 | 24.97 | 17.97 | 14.17 | 16.59 | 12.49 | 8.27 | 8.23 |
| NDVP-104 | 64.24 | 61.55 | 48.78 | 44.80 | 55.36 | 41.95 | 17.27 | 17.10 | 17.43 | 22.00 | 20.63 | 11.87 | 11.05 | 9.82 | 7.97 | 7.43 |
| Pusa pragati | 61.98 | 56.82 | 45 | 41.96 | 75.51 | 59.53 | 21.53 | 15.07 | 21.17 | 25.30 | 16.83 | 12.43 | 17.27 | 13.65 | 8.2 | 7.87 |
| Kashi ageti | 63.21 | 60.97 | 46.64 | 44.34 | 76.64 | 62.74 | 24.93 | 19.40 | 21.43 | 23.17 | 19.57 | 18.03 | 18.47 | 14.75 | 8.57 | 8.69 |
| Punjab-89 | 67.75 | 59.32 | 48.05 | 44.65 | 60.25 | 48.12 | 18.1 | 17.00 | 16.68 | 22.20 | 19.93 | 17.77 | 16.22 | 11.41 | 8.33 | 7.90 |
| KS-210 | 67.91 | 57.84 | 46.07 | 43.75 | 76.56 | 67.91 | 12.8 | 9.90 | 16.33 | 16.27 | 8.67 | 9.30 | 9.59 | 8.58 | 7.37 | 6.56 |
| Arka chaitra | 68.47 | 63.56 | 53.85 | 49.53 | 99.21 | 84.55 | 16.23 | 13.47 | 18.4 | 19.63 | 13.73 | 9.80 | 10.41 | 11.98 | 7.03 | 6.07 |
| Arka ajit | 68.33 | 62.29 | 53.02 | 49.89 | 89.37 | 73.82 | 16.17 | 13.33 | 16.47 | 18.70 | 13.13 | 10.63 | 15.32 | 11.96 | 8.3 | 7.79 |
| Mean | 66.35 | 60.74 | 49.84 | 46.67 | 69.18 | 57.29 | 15.22 | 12.60 | 17.78 | 20.20 | 13.23 | 10.97 | 11.38 | 9.30 | 7.39 | 6.92 |
| C.V. (%) | 4.84 | 3.97 | 2.88 | 2.82 | 15.38 | 13.62 | 9.5 | 8.16 | 8.75 | 11.38 | 9.82 | 8.79 | 12.72 | 11.37 | 5.83 | 5.66 |
| S.E. (m) | 1.85 | 1.39 | 0.83 | 0.76 | 6.14 | 4.51 | 0.83 | 0.59 | 0.9 | 1.33 | 0.75 | 0.56 | 0.84 | 0.61 | 0.25 | 0.23 |
| C.D. 5% | 5.25 | 3.94 | 2.35 | 2.15 | 17.42 | 12.77 | 2.37 | 1.68 | 2.55 | 3.76 | 2.13 | 1.58 | 2.37 | 1.73 | 0.7 | 0.64 |
| C.D. 1% | 6.99 | 5.25 | 3.13 | 2.87 | 23.2 | 17.01 | 3.15 | 2.24 | 3.39 | 5.01 | 2.83 | 2.10 | 3.16 | 2.31 | 0.94 | 0.85 |

DM: Days to maturity; DFI: Days to flower initiation; PH: Plant height; NNPP: Number nodules per plant; RL: Root length; BPP: Branches per plant; Pods per plant; SPP: Seeds per plant.

**Table 3.2:** Mean performance of vegetable pea genotypes under normal and drought conditions.

| Characters | PYPP | | SY | | BY | | HI | | SH (%) | | Catalase | | Proline | | Peroxidase | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Genotypes | N | D | N | D | N | D | N | D | N | D | N | D | N | D | N | D |
| Kashi samridhi | 60.73 | 42.27 | 28.08 | 26.37 | 151.14 | 109.64 | 40.14 | 38.77 | 49.6 | 46.40 | 9.39 | 12.49 | 12.01 | 16.90 | 62.21 | 75.92 |
| Kashi mukti | 67.73 | 49.63 | 25.85 | 23.65 | 159.75 | 124.17 | 42.51 | 39.60 | 50.6 | 47.24 | 10.39 | 12.48 | 10.92 | 15.99 | 64.44 | 78.81 |
| RPCAU-23-17 | 80.97 | 30.07 | 28.25 | 26.93 | 182.23 | 88.13 | 44.49 | 34.30 | 43.2 | 39.42 | 9.63 | 10.71 | 7.55 | 19.63 | 50.8 | 65.83 |
| DVP-8 | 54.97 | 39.87 | 17.57 | 14.82 | 148.75 | 110.75 | 36.96 | 36.36 | 45.57 | 40.80 | 9.07 | 11.01 | 7.02 | 12.48 | 49.19 | 59.59 |
| RPCAU-23-5 | 68.73 | 40.43 | 21.45 | 1 7.72 | 160.31 | 110.66 | 42.9 | 36.71 | 43.06 | 39.61 | 10.49 | 14.85 | 8.4 | 11.48 | 56.64 | 69.11 |
| RPCAU-23-9 | 68.97 | 42.90 | 16.44 | 14.12 | 194.5 | 125.49 | 35.59 | 34.96 | 39.65 | 37.97 | 9.78 | 12.46 | 6.37 | 12.00 | 57.18 | 69.50 |
| Pea 18503656 | 63.5 | 33.50 | 21.04 | 18.18 | 158.84 | 106.31 | 39.81 | 30.33 | 41.3 | 38.65 | 9.01 | 12.74 | 4.61 | 17.08 | 56.72 | 66.72 |
| AP-1 | 53.43 | 46.50 | 29.3 | 25.34 | 136.06 | 116.14 | 39.28 | 39.67 | 47.64 | 44.04 | 11.33 | 15.58 | 5.22 | 19.58 | 68.97 | 75.62 |
| Arkel | 58.13 | 40.83 | 25.36 | 23.76 | 154.68 | 117.16 | 37.63 | 35.47 | 40.45 | 40.20 | 8.33 | 13.97 | 4.91 | 18.94 | 65.38 | 79.77 |
| Saloni | 57.67 | 38.87 | 21.71 | 18.12 | 129.07 | 110.11 | 44.44 | 35.83 | 38.5 | 37.96 | 8.72 | 15.90 | 9.86 | 12.67 | 51.36 | 54.96 |
| AP-3 | 62.83 | 61.23 | 29.29 | 27.16 | 156.62 | 157.21 | 40.13 | 38.91 | 47.03 | 45.33 | 12.61 | 14.63 | 7.07 | 19.62 | 66.26 | 74.40 |
| Kashi uday | 52.63 | 33.83 | 30 | 27.94 | 133.76 | 96.34 | 39.42 | 35.66 | 49.56 | 45.34 | 13.62 | 14.50 | 10.54 | 11.73 | 50.45 | 61.14 |
| Arka priya | 77.47 | 60.83 | 28.93 | 26.15 | 179.08 | 164.02 | 43.31 | 37.37 | 44.93 | 41.00 | 9.62 | 12.25 | 8.95 | 18.89 | 55.17 | 65.15 |
| Arka uttam | 63.03 | 40.77 | 30.65 | 27.49 | 143.13 | 112.80 | 44.05 | 36.52 | 42.79 | 40.23 | 11.13 | 12.63 | 10.84 | 17.89 | 66.52 | 78.61 |
| VL-3 | 60.37 | 45.90 | 26.4 | 24.86 | 173.15 | 117.84 | 34.82 | 39.50 | 47.55 | 45.22 | 10.79 | 13.29 | 11.3 | 12.77 | 56.97 | 87.06 |
| RPCAU-23-11 | 53.8 | 30.03 | 20.1 | 17.75 | 138.22 | 87.85 | 38.9 | 34.96 | 44.45 | 42.88 | 9.96 | 12.28 | 9.08 | 9.42 | 60.43 | 69.13 |
| RPCAU-23-16 | 52.47 | 40.10 | 23.89 | 20.51 | 130.36 | 114.62 | 40.27 | 35.14 | 43.76 | 42.56 | 12.34 | 14.17 | 13.77 | 20.18 | 55.59 | 76.45 |
| Snow pea | 54.6 | 32.47 | 24.21 | 21.42 | 127.23 | 86.56 | 42.82 | 37.81 | 43.31 | 42.02 | 8.84 | 11.21 | 10.95 | 16.50 | 49.74 | 75.94 |
| NS-1100 | 71.9 | 57.40 | 28.31 | 24.70 | 162.3 | 136.98 | 44.44 | 41.05 | 44.01 | 42.32 | 10.03 | 12.22 | 6.49 | 10.54 | 58.87 | 69.27 |
| KSP-110 | 65.07 | 49.47 | 26.65 | 22.43 | 180.07 | 149.99 | 36.09 | 33.84 | 42.37 | 40.24 | 14.71 | 16.43 | 7.48 | 16.74 | 72.42 | 95.23 |
| Kashi nandini | 78.43 | 62.67 | 29.08 | 26.69 | 164.29 | 154.80 | 47.79 | 40.07 | 49.78 | 45.95 | 14.55 | 15.43 | 11.84 | 18.04 | 68.63 | 85.05 |
| NDVP-104 | 60.23 | 41.83 | 27.81 | 25.10 | 158.68 | 114.84 | 38.09 | 36.70 | 50.09 | 40.99 | 11.71 | 13.32 | 10.11 | 19.65 | 71.82 | 91.55 |
| Pusa pragati | 54.83 | 43.87 | 30.27 | 26.64 | 146.15 | 116.72 | 37.55 | 37.55 | 51.34 | 47.75 | 14.04 | 17.38 | 12.14 | 18.43 | 70.51 | 89.33 |
| Kashi ageti | 89.43 | 73.00 | 29.14 | 25.13 | 184.1 | 174.62 | 48.56 | 41.48 | 50.37 | 47.64 | 14.74 | 18.04 | 7.65 | 15.46 | 67.25 | 77.29 |
| Punjab-89 | 86.37 | 65.73 | 29.22 | 26.34 | 177.55 | 157.45 | 48.63 | 41.85 | 49.43 | 45.93 | 13.43 | 15.57 | 12.65 | 18.84 | 54.59 | 67.68 |
| KS-210 | 46.67 | 33.53 | 29.71 | 24.73 | 125.3 | 95.05 | 37.28 | 35.46 | 46.25 | 43.46 | 12.57 | 13.76 | 9.71 | 9.33 | 49.16 | 66.59 |
| Arka chaitra | 50.97 | 32.93 | 28.21 | 25.18 | 125.25 | 93.08 | 40.66 | 35.84 | 45.05 | 42.82 | 14.66 | 15.87 | 8.01 | 10.99 | 51.97 | 66.55 |
| Arka ajit | 61.6 | 37.27 | 29.42 | 26.92 | 142.68 | 93.21 | 43.26 | 39.34 | 47.94 | 44.95 | 13.03 | 15.36 | 6.88 | 12.38 | 52.77 | 67.34 |
| Mean | 63.48 | 44.56 | 26.3 | 23.43 | 154.4 | 119.38 | 41.07 | 37.18 | 45.7 | 42.82 | 11.38 | 13.95 | 9.01 | 15.50 | 59.36 | 73.56 |
| C.V. (%) | 11.05 | 9.81 | 7.56 | 8.86 | 4.62 | 6.06 | 11.04 | 9.13 | 7.55 | 8.90 | 7.71 | 8.03 | 5.64 | 6.04 | 4.98 | 5.39 |
| S.E. (m) | 4.05 | 2.52 | 1.15 | 1.20 | 4.12 | 4.18 | 2.62 | 1.96 | 1.99 | 2.20 | 0.51 | 0.65 | 0.29 | 0.54 | 1.71 | 2.29 |
| C.D. 5% | 11.48 | 7.16 | 3.26 | 3.40 | 11.67 | 11.84 | 7.42 | 5.55 | 5.65 | 6.24 | 1.44 | 1.83 | 0.83 | 1.53 | 4.84 | 6.49 |
| C.D. 1% | 15.29 | 9.53 | 4.34 | 4.53 | 15.54 | 15.77 | 9.88 | 7.40 | 7.53 | 8.31 | 1.91 | 2.44 | 1.11 | 2.04 | 6.44 | 8.64 |

PYPP: Pod yield per plant; SY: Seed yield; BY: Biological Yield; HI: Harvest index; SH: Shelling percentages.

**Days to maturity**

Under normal conditions, days to maturity ranged from 55.28 to 75.61, averaging 66.35, with Arka Ajit and Arka Chaitra maturing later than the check Kashi Nandini. Under drought, maturity ranged from 53.61 to 69.06, with a mean of 60.74, indicating shorter duration. This reduction aligns with earlier findings showing drought can shorten maturity by up to 33% due to forced maturation under heat and moisture stress (Lamichaney *et al*., 2021; Huang *et al*., 2023).

**Plant height**

Under normal conditions, plant height ranged from 48.43 to 103.12 cm, averaging 69.18 cm, whereas under drought it declined to 40.06-84.54 cm, with a mean of 57.29 cm. This reduction reflects growth suppression under water deficit. Similar reductions in pea height under drought were reported by Devi *et al*. (2025) and Vinarao *et al*. (2024), who attributed the decline to impaired growth rate and physiological functions.

**Number of branches per plant**

Under normal conditions, branch numbers ranged from 5.83 to 20.63, with a mean of 13.24, while under drought, they declined to 4.17-18.03, averaging 8.79. DVP-8 recorded the fewest branches in both conditions, whereas NDVP-104 and Kashi Ageti showed the highest under normal and drought conditions, respectively. The reduction under drought agrees with Soni *et al*. (2022), reflecting a stress-induced strategy to conserve resources.

**Number of pods per plant**

Under normal conditions, pods per plant ranged from 6.40 to 18.47, with a mean of 11.38, whereas under drought, they declined to 6.07-14.75, averaging 9.30. Kashi Ageti produced the most pods in both environments. The reduction under drought likely results from stress during flowering and pod filling. Kumar *et al*. (2024b); Sharma *et al*. (2025), similarly, reported that drought decreases pod-bearing nodes and peas per pod, reducing overall pod number.

**Seed count per pod**

Under normal conditions, seeds per pod ranged from 5.90 to 9.23, averaging 7.39, with RPCAU-23-17, KSP-110 and Kashi Ageti outperforming the check Kashi Nandini. Under drought, the range declined to 5.60-8.69, with a mean of 6.92 and Kashi Ageti remained superior. Drought reduced seed numbers, likely due to impaired cell division and expansion, a trend also reported by Prudent *et al*. (2016).

**Seed yield**

Under normal conditions, seed yield ranged from 16.44 g to 30.65 g, with a mean of 26.30 g, whereas under drought it declined to 14.12-27.94 g, averaging 23.43 g. This reduction indicates the strong negative impact of water deficit on yield. Earlier studies also highlight that drought and high temperatures during flowering and pod development can severely reduce productivity, causing yield losses of up to 60% in peas (Huang *et al*., 2023; Yücel, 2018).

**Root length**

Under normal conditions, root length varied from 9.62 cm (RPCAU-23-9) to 26.10 cm (Kashi Samridhi), with a general mean of 17.78±0.90 cm. Under drought conditions, root length ranged from 12.67 cm (DVP-8) to 27.83 cm (Kashi Samridhi), with a general mean of 20.20±1.33 cm. The results indicate that pea plants tend to exhibit increased root length under drought conditions. Yathish *et al*. (2021) reported similar findings. These results highlight that root length may increase under drought as an adaptive response.

**Biological yield**

Under normal conditions, biological yield ranged from 125.25 g (Arka Chaitra) to 194.50 g (RPCAU-23-9), with a general mean of 154.40±4.12 g. Under drought conditions, biological yield ranged from 86.56 g (Pea 18503656) to 174.62 g (Kashi Ageti), with a general mean of 119.38± 4.18 g. The biological yield of the vegetable pea significantly decreased under drought conditions compared to normal conditions. Hero *et al*. (2024) reported similar findings in their study.

**Shelling percentage**

Under normal conditions, shelling percentage ranged from 38.50% to 51.34% (mean 45.70%), while under drought it declined to 37.96-47.75% (mean 42.82%). All genotypes showed reduced shelling under stress, consistent with Yathish *et al*. (2021).

**Pod yield per plant (g)**

Under normal conditions, pod yield per plant ranged from 46.67 to 89.43 g (mean 63.48 g), while under drought it declined to 30.03-73.00 g (mean 44.56 g). Drought significantly reduced yield, consistent with reports of 40-50% losses during flowering stress (Kumar *et al*., 2024a; Bénézit *et al*., 2017; Sharma *et al*., 2025).

**Harvest index**

Under normal conditions, harvest index ranged from 34.82% to 48.63%, averaging 41.07%, while under drought it declined to 30.33-41.85%, with a mean of 37.18%. The reduction reflects limited seed formation and biomass accumulation under water deficit. Similar trends have been reported in legumes, with pod harvest index decreasing under severe stress in common beans (Shamsaee *et al*., 2025) and peas (Assefa *et al*., 2013).

**Performance of genotypes based on biochemical traits**

Vegetable pea genotypes showed significant variation in biochemical traits under both normal and drought conditions, indicating genetic diversity in responses. (Table 3.2).

**Proline content**

Under normal conditions, proline content ranged from 4.61 to 13.77 µmol/g, averaging 9.01 µmol/g, whereas under drought it increased to 9.33-20.18 µmol/g, with a mean of

15.50 µmol/g. This significant rise reflects a typical stress response, as proline helps plants adjust osmotically, protect cellular structures and scavenge reactive oxygen species. Similar dramatic increases, sometimes up to tenfold, have been reported under water deficit in peas and other crops (Mafakheri *et al*., 2010; Kardile *et al*., 2018; Lahuta *et al*., 2022; Arafa *et al*., 2021).

**Catalase content**

Under normal conditions, catalase content ranged from 8.33 to 14.74 µmol/min/g, averaging 11.38 µmol/min/g, whereas under drought it increased to 10.71-18.04 µmol/min/g, with a mean of 13.95 µmol/min/g. This significant rise under stress reflects the plant's antioxidant defense response, helping to detoxify reactive oxygen species generated during drought, as reported in previous studies (Osman, 2015; Sarker and Oba, 2018).

**Peroxidase activity**

Under normal conditions, peroxidase activity ranged from 49.16 to 72.42 µmol/min/g, averaging 53.36 µmol/min/g, whereas under drought it increased to 54.96-95.23 µmol/min/g, with a mean of 73.56 µmol/min/g. This significant rise reflects the plant's response to enhanced oxidative stress, as increased peroxidase activity helps scavenge reactive oxygen species and mitigate cellular damage under drought conditions (Osman, 2015; Sivaprakasam and Rajasekaran, 2025).

**Analysis of performance based on drought tolerance indices**

Analysis of drought tolerance indices showed DTI ranging from 0.347-1.221 (mean 0.9152), DSI from 0.425-1.619 (mean 1.0085) and TI from 1.328-4.980 (mean 2.8635). Genotypes with high DTI and TI but low DSI are considered drought tolerant. Based on these indices, Kashi Samridhi, RPCAU-23-17, Kashi Uday, KSP-210 and AP-1 were identified as promising drought-tolerant pea genotypes (Couchoud *et al*., 2020; Jiang *et al*., 2023).

**Categorisation of vegetable pea genotypes based on drought tolerance indices**

Drought tolerance indices were estimated based on the seed yield per plant of genotypes under drought conditions in comparison to normal conditions. Three indices, namely, Drought Tolerance Index (DTI), Drought Susceptibility Index (DSI) and Tolerance Index (TI), were estimated and compared among the genotypes under evaluation in the present study (Table 4).

**Based on drought tolerance index (DTI)**

The 28 genotypes were categorised into highly drought-tolerant, low drought-tolerant and moderately drought-tolerant. Accordingly, the highly drought-tolerant genotypes include Kashi Samridhi, RPCAU-23-17, AP-1, AP-3, Kashi Uday, Arka Priya, Arka Uttam, Kashi Nandini, Pusa Pragati, Kashi Ageti, PUNJAB-89, KS-210 and Arka Ajit. Genotypes with low drought tolerant index DVP-8, RPCAU-23-5, RPCAU-23-9, Pea 18503656, Saloni, RPCAU-23-11, RPCAU-23-16 and Snow Pea. On the other hand, genotypes with a drought-tolerant index include Arka Chaitra, NDVP-104, KSP-110, NS-1100, VL-3, Arkel and Kashi Mukti.

**Based on the drought susceptibility index (DSI)**

A total of 28 genotypes were categorised into highly drought-susceptible, less drought-susceptible and moderately drought-susceptible. Accordingly, the highly drought susceptible genotypes include DVP-8, RPCAU-23-5, Pea 18503656, AP-1, Saloni, RPCAU-23-16, KSP-110, Kashi Ageti, KS-210. Genotypes with low drought susceptibility index include Kashi Samridhi, Kashi Mukti, RPCAU-23-17, Arkel, AP-3, Kashi Uday, VL-3, Kashi Nandini and Arka Ajit. On the other hand, genotypes with a Drought Susceptibility Index include RPCAU-23-9, Arka Priya, Arka Uttam, RPCAU-23-11, Snow pea, NS-1100, NDVP-104, Pusa Pragati, Punjab-89 and Arka Chaitra.

**Table 4:** Performance of selected pea genotypes evaluated for drought tolerance.

| Genotypes | DTI | DSI | TI |
|---|---|---|---|
| Kashi samridhi | 1.079 | 0.571 | 1.716 |
| Kashi mukti | 0.881 | 0.694 | 2.203 |
| Kashi udai | 1.214 | 0.628 | 2.057 |
| Kashi nandini (Check) | 1.123 | 0.749 | 2.387 |
| Kashi ageti | 1.057 | 1.244 | 4.013 |
| VL-3 | 0.952 | 0.53 | 1.537 |
| AP-3 | 1.152 | 0.672 | 2.137 |
| AP-1 | 1.075 | 1.245 | 3.966 |
| Pea 18503656 (Mollo) | 0.556 | 1.245 | 2.855 |
| KS-210 | 1.066 | 1.543 | 4.98 |
| NDVP-104 | 1.013 | 0.878 | 2.707 |
| Saloni | 0.569 | 1.484 | 3.597 |
| Arka priya | 1.094 | 0.865 | 2.178 |
| Arka uttam | 1.221 | 0.956 | 3.16 |
| Arka chaitra | 1.033 | 0.975 | 3.027 |
| Arka ajit | 1.148 | 0.779 | 2.503 |
| Pusa pragati | 1.172 | 1.124 | 3.623 |
| Arkel | 0.877 | 0.573 | 1.593 |
| Punjab-89 | 1.115 | 0.908 | 2.883 |
| KSP-110 | 0.865 | 1.406 | 4.213 |
| Snow pea | 0.75 | 1.048 | 2.787 |
| NS-1100 | 1.011 | 1.114 | 3.61 |
| DVP-8 | 0.378 | 1.407 | 2.747 |
| RPCAU-23-5 | 0.551 | 1.609 | 3.75 |
| RPCAU-23-9 | 0.337 | 1.168 | 2.317 |
| RPCAU-23-11 | 0.517 | 1.071 | 2.35 |
| RPCAU-23-16 | 0.718 | 1.327 | 3.381 |
| RPCAU-23-17 | 1.102 | 0.425 | 1.318 |
| Mean | 0.9152 | 1.0085 | 2.8635 |
| SD | 0.2586 | 0.3269 | 0.8723 |
| Range | 0.347 -1.221 | 0.425 -1.619 | 1.328 -4.980 |

DTI: Drought tolerance index; DSI: Drought susceptibility index; TI: Tolerance index.

### Based on tolerance index

The 28 genotypes were categorised into high tolerance index, low tolerance index and moderately tolerance index. Accordingly, the High Tolerance Index values of genotypes include RPCAU-23-5, AP-1, Saloni, RPCAU-23-16, NS-1100, KSP-110, Pusa Pragati, Kashi Ageti and KS-210. Genotypes with low values of the Tolerance Index include Kashi Samridhi, Kashi Mukti, RPCAU-23-17, RPCAU-23-9, Arkel, AP-3, Kashi Uday, VL-3 and RPCAU-23-11. On the other hand, genotypes with values of Tolerance Index include DVP-8, Pea 18503656, Arka Priya, Arka Uttam, Snow pea, NDVP-104, Punjab-89, Kashi Nandini, Arka Chaitra and Arka Ajit.

## CONCLUSION

The evaluation of 28 vegetable pea genotypes under normal and drought conditions showed considerable variability in drought tolerance. Drought significantly reduced all agronomic traits, yet genotypes such as RPCAU-23-5, KSP-110, Arka Chaitra and Kashi Udai performed better, maintaining higher yields, pod numbers, plant height and root length. In contrast, the check variety Kashi Nandini exhibited a 48% yield reduction. Genotypes with higher drought tolerance index and lower drought susceptibility and tolerance indices were identified as highly resilient. Further molecular studies are essential to elucidate drought-related genes and support breeding of climate-resilient vegetable pea cultivars.

### Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarilyrepresent the views of their affiliated institutions. The authors are responsible for the accuracy andcompleteness of the information provided, but do not accept any liability for any direct or indirect lossesresulting from the use of this content.

### Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. Nofunding or sponsorship influenced the design of the study, data collection, analysis, decision to publish,or preparation of the manuscript.

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