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RESEARCH ARTICLE

# Genetic variability and selection strategies for yield improvement in water spinach (*Ipomoea aquatica*) under upland field conditions

**Kanchhi Maya Waiba[1], A. K. Singh[1], Rakesh K. Dubey[2*], Anjana Sisodia[1], N. Rai[2] and Rajesh Kumar[2]**

## Abstract
The present study was conducted during 2023 and 2024 to assess the extent of genetic variation and identify promising genotypes for yield and growth-related traits. Over 25 genotypes, including a variety 'Kashi Manu', were evaluated under a randomized block design with three replications. The analysis of variance revealed highly significant differences among genotypes for all the studied traits, indicating substantial genetic variability. Wide ranges were recorded for key parameters such as days to 50% germination (2.39–4.56 days), plant height at 30 DAS (43.50–69.90 cm), stem diameter at 30 DAS (6.54–10.76 mm) and leaf biomass yield per plant per month (0.67–1.68 kg). High heritability coupled with high genetic advance was observed for internodal length, stem diameter (30 DAS) and biomass yield traits, suggesting predominance of additive gene action and effectiveness of direct selection. The genotypes VRWS-32, VRWS-28, VRWS-33, VRWS 41-23 and VRWS 42-23 exhibited superior yield performance, comparable to the check variety. These findings indicate ample genetic potential within the evaluated germplasm and emphasize the scope for selection-based improvement to develop high-yielding, upland-adapted water spinach varieties.

**Keywords**: Selection, Genetic variability, Heritability, Genetic advance, Yield.

[1]Banaras Hindu University, Institute of Agricultural Sciences, Varanasi-221005

[2]ICAR-Indian Institute of Vegetable Research, Varanasi-221305

[*]**Corresponding author;** Email: rksdubey@gmail.com

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## Introduction
Water spinach is a crucial leafy vegetable commonly found across Asia and in parts of Africa and Latin America for its rapid growth, nutritive value, high biomass yield and its role in smallholder and peri-urban markets (Purayil et al., 2025). Recent advances in genomics and molecular resources for water spinach have improved our understanding of species relationships and trait loci, creating new scope for breeding and trait-targeted selection. Historically, water spinach has been cultivated in aquatic/semi-aquatic systems, which expose the crop to specific abiotic and biotic pressures, including heavy-metal contamination and variable waterborne pathogens. To improve food safety and expand production area, there is a growing shift toward upland cultivation and conventional soil-based production. This cultivation decreases some contamination risks but exposes genotypes to a different suite of stresses that might alter yield expression and quality traits (Qi et al., 2024). Current initiatives at ICAR-IIVR, Varanasi, to introduce water spinach cultivation under upland field conditions have produced promising results, showing its potential for wider adoption beyond traditional aquatic systems (Dubey et al., 2022). Despite the crop's socio-economic value and these management trends, systematic information on genetic variability, heritability and trait associations for yield under

upland field conditions remains inadequate compared with major leafy vegetables. Marker-based surveys and recent genetic studies indicate appreciable intra-specific diversity in water spinach; however, most genetic characterizations and breeding reports have intensive on aquatic ecotypes on single traits, creating a gap for breeding programs targeting upland adaptation and yield improvement. Filling this gap is crucial because the magnitude and pattern of genetic variation determine the efficiency of assortment and the likely genetic gain for complex traits like biomass yield and harvest index. Quantitative genetic tools, estimation of phenotypic and genotypic coefficients of variation (PCV/GCV), broad and narrow sense heritability, trait correlations, genetic advance, path analysis, etc., are essential for recognizing promising parental lines, selecting actual selection indices and prioritizing component traits that most strongly and reliably affect yield under target upland conditions (Bidyananda, 2024). Hence, this study seeks to quantify genetic variability, heritability and genetic advance for yield and crucial yield-attributing traits among diverse water spinach genotypes under upland field conditions andto develop and validate selection indices and recommendation strategies for early-generation selection targeted at upland adaptability and food-safe, high-biomass production. This investigation will provide breeder-usable information to accelerate selection for upland-adapted, high-yielding cultivars and to guide future molecular and agronomic integration for this increasingly important leafy vegetable, water spinach.

## Materials and Methods

Field experiments were conducted during 2023 and 2024 at the Experimental Farm of the ICAR-Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh, India (25.10 °N latitude, 82.52 °E longitude and the overall mean temperature was 20.8°C to 29.4 ± 4 °C). The trials were performed under upland field conditions using a Randomized Complete Block Design with three replications. Twenty-four genotypes of water spinach (VRWS-32, VRWS-28, VRWS-33, VRWS-31, VRWS-40-23, VRWS-41-23, VRWS-42-23, VRWS-43-23, VRWS-44-23, VRWS-45-23, VRWS-46-23, VRWS-47-23, VRWS-48-23, VRWS-49-23, VRWS-50-23, VRWS-51-23, VRWS-52-23, VRWS-54-23, VRWS-55-23, VRWS-53-23, VRWS-Red, VRWS-56-23, VRWS-57-23, VRWS-58-23) and 1 check variety Kashi Manu were included in the study. Seeds were sown directly in the main field without nursery raising. Three seeds of each genotype were sown per hill at a spacing of 20×10cm. After complete germination, a single healthy seedling was retained per hill and others were removed. Each replication comprised 60 plants/genotype. Well-decomposed farmyard manure was incorporated during the first ploughing @2.5 kg/m². A basal dose of NPK fertilizer was applied at 5:3:3 g/m² during field preparation. Irrigation was provided through a furrow system immediately after sowing and subsequently at 5 to 7 day intervals based on crop requirements. For the data recording, five plants of each genotype were randomly tagged in each replication and the observations were recorded on days to 50% germination (Waiba and Sharma 2020), plant height at 10 DAS, 20 DAS and 30 DAS(cm), stem diameter at 10 DAS and 30 DAS (mm), days to first harvesting at about 27 to 30 cm plant height, leaf biomass yield/plant/month (kg), leaf biomass yield/m² area/month (kg), emergence of vines/plant during 1st harvesting, emergence of vines after 10 cuttings, number of nodes/plant, number of cuttings/month, leaf width (cm), petiole length (cm), leaf length (cm), internodal length (cm), leaf shape and flower colour.

### *Statistical analysis*

The recorded data for different traits were subjected to statistical analysis to determine the analysis of variance and mean performance as described by Panse and Sukhatme (1984). The genotypic and phenotypic coefficients of variation (GCV and PCV), heritability in the broad sense ($h^2$bs) and genetic advance (GA) were estimated based on Burton and DeVane's (1953) and Johnson et al. (1955) method, using the statistical software OPSTAT.

## Result and Discussion

### *Analysis of variance for the experimental design*

The values of mean sum of squares of analysis of variance of the pooled data (2023 and 2024)showed highly significant differences among the evaluated water spinach genotypes for all the traits studied *viz*., days to 50% germination, plant height at 10, 20 and 30DAS, stem diameter at 10 and 30 DAS, days to first harvesting, leaf biomass yield/plant/month, leaf biomass yield/square meter/month, emergence of vines during first harvesting, emergence of vines/plant after 10 cuttings, number of nodes/plant, number of cuttings/month, leaf width, petiole length, leaf length and internodal length (Fig 1). The presence of large genetic variability forms the fundamental basis for successful selection, as it develops the scope of identifying superior genotypes for future breeding efforts (Burton & DeVane, 1953). These results are similar to earlier reports in leafy vegetables, including water spinach, where significant genotypic variability has been observed among various yield attributing and vegetative traits (Sarkar et al., 2014).

### *Mean performance of genotypes*

The days to 50% germination were recorded between 2.39 and 4.56 days (Table 1). The mean performance showed that genotype VRWS 46-23 (2.43) and VRWS 48-23 (2.43), VRWS 44-23 (2.53), VRWS-31 (2.57) and VRWS 47-23 (2.65) were statistically at par with respect to days to 50% germination. Present findings are closer to the reports of Rao (2000) for

**Table 1:** Mean performance of water spinach genotypes for the yield and yield attributing traits pooled data (2023 - 2024)

| Genotypes | *Days to 50% germi-nation* | *Plant height in 10 DAS (cm)* | *Plant height in 20 DAS (cm)* | *Plant height in 30 DAS (cm)* | *Stem diameter in 10 DAS (mm)* | *Stem diameter in 30 DAS (mm)* | *Days to1st harves-ting* | *Leaf biomass yield/ plant/ month (kg)* | *Leaf biomass yield/m²/ month (kg)* | *Emergence of vines/ pant (during 1st harvesting)* | *Emergence of vines/ plant (after 10 cuttings)* | *No. of nodes/ plant* | *No. of cuttings/ month* | *Leaf width (cm)* | *Petiole length (cm)* | *Leaf length (cm)* | *Internodal length (cm)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VRWS-32 | 3.08 | 16.36 | 36.07 | 50.234 | 3.03 | 9.10 | 15.50 | 1.66 | 6.73 | 4.63 | 30.12 | 13.72 | 3.75 | 4.79 | 5.35 | 13.30 | 4.60 |
| VRWS-28 | 2.99 | 16.45 | 31.75 | 46.91 | 2.93 | 10.05 | 18.83 | 1.66 | 6.77 | 4.45 | 30.44 | 15.38 | 3.49 | 4.56 | 4.95 | 13.30 | 3.58 |
| VRWS-33 | 2.78 | 16.38 | 35.70 | 63.13 | 2.88 | 9.76 | 16.50 | 1.60 | 6.43 | 4.38 | 28.11 | 17.79 | 4.71 | 4.60 | 5.43 | 12.04 | 3.66 |
| VRWS-31 | 2.57 | 15.61 | 34.66 | 59.30 | 3.00 | 9.58 | 17.33 | 1.40 | 5.61 | 3.91 | 23.72 | 17.00 | 4.41 | 5.07 | 5.02 | 12.66 | 3.73 |
| VRWS 40-23 | 2.97 | 14.76 | 31.77 | 55.30 | 3.15 | 10.76 | 19.33 | 1.48 | 5.93 | 4.66 | 30.77 | 17.12 | 4.12 | 5.23 | 4.86 | 12.25 | 3.26 |
| VRWS 41-23 | 3.18 | 15.58 | 34.20 | 53.93 | 3.06 | 10.31 | 17.66 | 1.52 | 6.10 | 4.23 | 23.83 | 15.55 | 4.02 | 5.13 | 5.43 | 13.86 | 3.90 |
| VRWS 42-23 | 3.39 | 14.56 | 31.74 | 55.63 | 3.05 | 9.83 | 18.83 | 1.61 | 6.44 | 3.94 | 27.49 | 14.61 | 4.14 | 5.91 | 5.60 | 13.21 | 3.61 |
| VRWS 43-23 | 3.39 | 15.80 | 33.55 | 55.23 | 2.93 | 8.60 | 18.16 | 1.30 | 5.21 | 3.53 | 24.38 | 15.62 | 4.12 | 5.70 | 5.60 | 12.29 | 2.76 |
| VRWS 44-23 | 2.53 | 15.98 | 32.89 | 53.46 | 3.16 | 8.95 | 18.33 | 1.41 | 5.73 | 4.36 | 25.11 | 15.82 | 3.99 | 5.59 | 5.22 | 13.44 | 2.98 |
| VRWS 45-23 | 3.56 | 15.46 | 33.21 | 46.88 | 3.06 | 9.95 | 18.50 | 1.13 | 4.54 | 4.49 | 23.33 | 15.39 | 3.49 | 5.75 | 5.00 | 13.20 | 2.78 |
| VRWS 46-23 | 2.43 | 15.98 | 31.99 | 57.35 | 3.07 | 9.90 | 19.00 | 1.42 | 5.69 | 3.89 | 25.00 | 15.33 | 4.27 | 5.97 | 5.12 | 13.95 | 2.75 |
| VRWS 47-23 | 2.65 | 14.65 | 32.92 | 53.19 | 3.02 | 9.63 | 18.50 | 1.49 | 5.96 | 4.64 | 23.49 | 15.92 | 3.96 | 6.64 | 4.68 | 13.62 | 3.73 |
| VRWS 48-23 | 2.43 | 17.55 | 34.43 | 51.81 | 3.10 | 8.91 | 17.00 | 1.14 | 4.55 | 4.56 | 24.61 | 15.80 | 3.85 | 6.90 | 5.34 | 13.49 | 3.78 |
| VRWS 49-23 | 3.30 | 17.28 | 35.33 | 50.15 | 2.95 | 8.83 | 16.66 | 1.26 | 5.07 | 4.54 | 24.03 | 16.99 | 3.73 | 6.27 | 5.93 | 13.57 | 3.38 |
| VRWS 50-23 | 3.47 | 14.20 | 32.48 | 65.21 | 3.03 | 9.70 | 18.83 | 1.33 | 5.35 | 4.32 | 28.22 | 14.77 | 4.86 | 6.03 | 5.68 | 13.06 | 4.75 |
| VRWS 51-23 | 3.36 | 14.31 | 31.28 | 69.90 | 2.96 | 9.30 | 19.16 | 1.15 | 4.63 | 4.36 | 23.16 | 15.38 | 5.21 | 6.01 | 5.96 | 12.58 | 5.11 |
| VRWS 52-23 | 3.70 | 15.61 | 30.27 | 62.10 | 3.18 | 8.86 | 20.00 | 1.40 | 5.62 | 4.21 | 25.81 | 15.72 | 4.64 | 5.25 | 5.22 | 11.84 | 4.45 |
| VRWS 54-23 | 2.73 | 16.10 | 28.09 | 56.86 | 2.59 | 4.80 | 19.16 | 0.81 | 3.25 | 3.40 | 17.40 | 13.74 | 4.23 | 4.43 | 4.06 | 11.11 | 5.06 |
| VRWS 55-23 | 3.54 | 13.15 | 32.40 | 65.81 | 2.70 | 4.51 | 18.50 | 0.77 | 3.09 | 4.22 | 16.94 | 16.76 | 4.90 | 4.97 | 3.84 | 9.22 | 6.03 |
| VRWS 53-23 | 3.43 | 13.78 | 27.60 | 56.48 | 2.85 | 5.36 | 19.66 | 0.70 | 2.80 | 3.80 | 17.14 | 19.77 | 4.21 | 4.12 | 4.26 | 7.69 | 3.96 |
| VRWS -Red | 4.14 | 14.20 | 29.85 | 57.35 | 2.68 | 4.68 | 19.33 | 0.95 | 3.80 | 4.21 | 19.55 | 17.28 | 4.27 | 4.33 | 4.81 | 8.20 | 6.31 |
| VRWS 56-23 | 4.56 | 15.50 | 26.55 | 61.88 | 2.78 | 4.55 | 21.33 | 0.69 | 2.77 | 3.85 | 16.32 | 20.76 | 4.60 | 4.10 | 4.52 | 9.04 | 5.36 |
| VRWS 57-23 | 4.56 | 15.50 | 31.76 | 59.35 | 2.95 | 9.25 | 19.66 | 1.12 | 4.50 | 3.61 | 23.74 | 15.99 | 4.42 | 4.03 | 5.41 | 9.53 | 6.98 |
| VRWS58-23 | 3.94 | 15.76 | 25.53 | 61.91 | 2.75 | 5.05 | 20.50 | 0.67 | 2.70 | 3.42 | 16.31 | 18.75 | 4.62 | 3.07 | 3.87 | 6.99 | 6.68 |
| Kashi Manu (Check) | 2.39 | 17.18 | 35.02 | 63.35 | 3.75 | 9.98 | 17.00 | 1.68 | 6.75 | 4.63 | 28.99 | 16.94 | 4.72 | 6.05 | 5.43 | 13.31 | 3.43 |
| Range | 2.39-4.56 | 13.15-17.55 | 25.53-36.07 | 46.88-69.90 | 2.58-3.75 | 4.51-10.76 | 15.50-21.33 | 0.67-1.68 | 2.70-5.04 | 3.40-4.66 | 16.31-30.77 | 13.72-20.76 | 3.94-5.21 | 3.07-6.90 | 3.84-5.96 | 6.99-13.95 | 2.71-6.98 |
| Mean | 3.17 | 15.51 | 32.05 | 57.31 | 2.98 | 8.34 | 18.55 | 1.24 | 4.97 | 4.22 | 23.92 | 16.32 | 4.27 | 5.19 | 5.05 | 11.87 | 4.26 |
| C.D. | 0.28 | 1.95 | 3.67 | 3.85 | 0.18 | 1.69 | 1.87 | 0.17 | 0.70 | 0.18 | 4.99 | 2.45 | 0.29 | 0.83 | 0.53 | 1.96 | 0.52 |
| SE(d) | 0.13 | 0.94 | 1.77 | 1.85 | 0.08 | 0.818 | 0.90 | 0.08 | 0.34 | 0.08 | 2.40 | 1.18 | 0.14 | 0.40 | 0.25 | 0.94 | 0.25 |
| C.V. | 4.34 | 6.08 | 5.52 | 3.23 | 2.97 | 9.722 | 4.85 | 6.57 | 6.75 | 2.14 | 10.04 | 7.25 | 3.29 | 7.71 | 5.11 | 7.98 | 5.87 |

spinach seeds germination within 2 to 5days under favorable temperature and moisture conditions. Early germination is a highly desirable trait in water spinach, as it leads to faster seedling establishment, reduces vulnerability to early-stage environmental stress and allows for quicker progression to harvest (Ibrahim et al., 2019). The genotype VRWS 48-23 recorded the maximum plant height at 10 DAS (17.55 cm) followed by VRWS 49-23 (17.28 cm), VRWS-28 (16.45 cm), VRWS-33 (16.38 cm), VRWS-32 (16.36 cm), VRWS 54-23 (16.10 cm), VRWS 44-23 and VRWS 46-23 (15.98 cm), VRWS 43-23 (15.80 cm), VRWS 58-23 (15.76 cm), VRWS-31 and VRWS 52-23 (15.61 cm) were at par with check (17.18 cm). Plant height at 10 DAS showed a mean value range from 13.15 to 17.55 cm and the present result corresponds to that of Rao (2000) in water spinach, i.e., about 15 cm in 10 days after sowing, especially in warm climates. The plant height in 20 days recorded a range of 25.53 to 36.07cm among the studied genotypes. The genotype VRWS-32 showed the greatest plant height at 20DAS (36.07 cm), followed by VRWS-33 (35.70 cm) and VRWS-49-23 (35.33 cm), which performed at par with the check (35.02 cm). Genotypes showing taller plant stature during early growth stages may develop more leaf area, facilitating enhanced photosynthetic activity and subsequently higher biomass production (Peng et al. 2024). Calub et al. (2022) stated water spinach reached 22to 25 cm in 20 days under field conditions. In this study, VRWS 51-23 showed the greatest plant height (69.90cm), representing superior vertical growth and probable advantages in light competition, canopy development and leaf yield under upland field conditions. Other genotypes, such as VRWS 55-23, VRWS 50-23, VRWS-33, VRWS 52-23, VRWS 58-23 and VRWS 56-23 performed comparably to the check. Marcelis et al. (1998) stated that early plant height in leafy vegetables can predict overall plant productivity, especially in crops subjected to multiple harvests. In terms of performance for stem diameter at 10DAS, no genotype noted a significantly thicker stem diameter than the check (3.75 mm). The range of 2.58 to 3.75 mm stem diameter was observed among the water spinach genotypes. This result was similar to the result reported in a hydroponic experiment by Alam et al. (2022) in water spinach seedlings, which ranged 2.0 to 3.0 mm at 10DAS. Stem diameter is a significant indicator of seedling vigor and overall plant health. The highest stem diameter at 30DAS was recorded in genotype VRWS 40-23 (10.76 mm) followed by VRWS 41-23 (10.31 mm), VRWS-28 (10.05 mm), VRWS 45-23 (9.95 mm), VRWS 46-23 (9.90 mm), VRWS 42-23 (9.83 mm), VRWS-33 (9.76 mm), VRWS 50-23 (9.70 mm), VRWS 47-23 (9.63 mm), VRWS-31 (9.58 mm), VRWS 51-23 (9.30 mm), VRWS 57-23 (9.25 mm) and VRWS-32 (9.10 mm) were found statistically at par with check (9.50 mm). A thicker stem is generally related to better nutrient and water translocation, as well as resistance to lodging, especially under repeated harvesting regimes. The genotype VRWS-32 observed the earliest maturity with minimum days to first harvest (15.50) followed by VRWS-33 (16.5), VRWS 49-23 (16.66), VRWS 48-23 (17.0), VRWS-31 (17.33), VRWS 41-23 (17.66), VRWS 43-23 (18.16), VRWS 44-23 (18.33), VRWS 45-23 (18.5), VRWS 47-23 (18.50), VRWS-28, VRWS 42-23 and VRWS 50-23 (18.83) were at par with check (17). Rao (2000) has observed that water spinach can reach 25 to 30 cm height in 20to 25 days under tropical field conditions, mainly in moist, fertile soil, which was closer to his statement. The mean performance for the trait leaf biomass yield/plant/month showed prominent variation, ranging from 0.67 to 1.68 kg. The check recorded the highest yield (1.68 kg), followed by VRWS-32 and VRWS-28 (both 1.66 kg), VRWS 42-23 (1.61 kg), VRWS-33 (1.60 kg) and VRWS-41-23 (1.52 kg) were statistically at par. Sarker et al. (2014) reported that high-yielding genotypes of water spinach are often characterized by vigorous vegetative growth, efficient leaf regeneration and higher leaf area index. The highest leaf biomass yield/square meter/month was recorded in VRWS-28 (6.77 kg), followed by VRWS-32 (6.73 kg), VRWS 42-23 (6.44 kg), VRWS-33 (6.43 kg) and VRWS-41-23 (6.10 kg), which were found to be statistically at par with the check (6.6 8 kg). These findings are consistent with Ramasamy et al. (2023), who reported that genotypes with higher plant vigor and leaf production capacity often lead to improved biomass accumulation over time. During first harvest, the mean number of vine emergences across the water spinach genotypes was 4.22 where the genotypes VRWS 40-23 (4.66), VRWS 47-23 (4.64), VRWS-32 (4.63), VRWS 48-23 (4.56), VRWS 49-23 (4.54), VRWS 45-23 (4.49) and VRWS-28 (4.45) recorded higher and at par with check (4.63). More vines is desirable trait for the higher yield. Calub et al. (2022) recorded that water spinach plants reaching 25cm height showed 2-3 lateral vines under upland field conditions, which is closer to the present findings. The genotypes exhibited significant variability for emergence of vines/plant after 10 cuttings, the highest number of vines/plant after 10 cuttings was recorded in VRWS 40-23 (30.77), followed by VRWS-28 (30.44), VRWS-32 (30.12) and check (28.99), showing superior regenerative ability and sustained biomass production over multiple harvests. More vine emergence is particularly desirable for commercial leafy vegetable production where repeated cuttings are practiced (Sarkar et al., 2014). The tested genotypes showed a number of nodes/plant ranging from 13.72 to 20.76nodes where the genotype VRWS 56-23 recorded the highest number of nodes (20.76), followed by VRWS 53-23 (19.77), which were significantly higher than the check (16.94). This result was found similar to the findings of Sarkar et al. (2014), who observed a number of nodes/plant ranging from 15.55 to 20.38 nodes. Significant variation was observed for the trait number of cuttings/month, the genotype VRWS 51-23 recorded the highest number of cuttings (5.21) which was significantly greater than all other evaluated genotypes including check whereas, genotypes

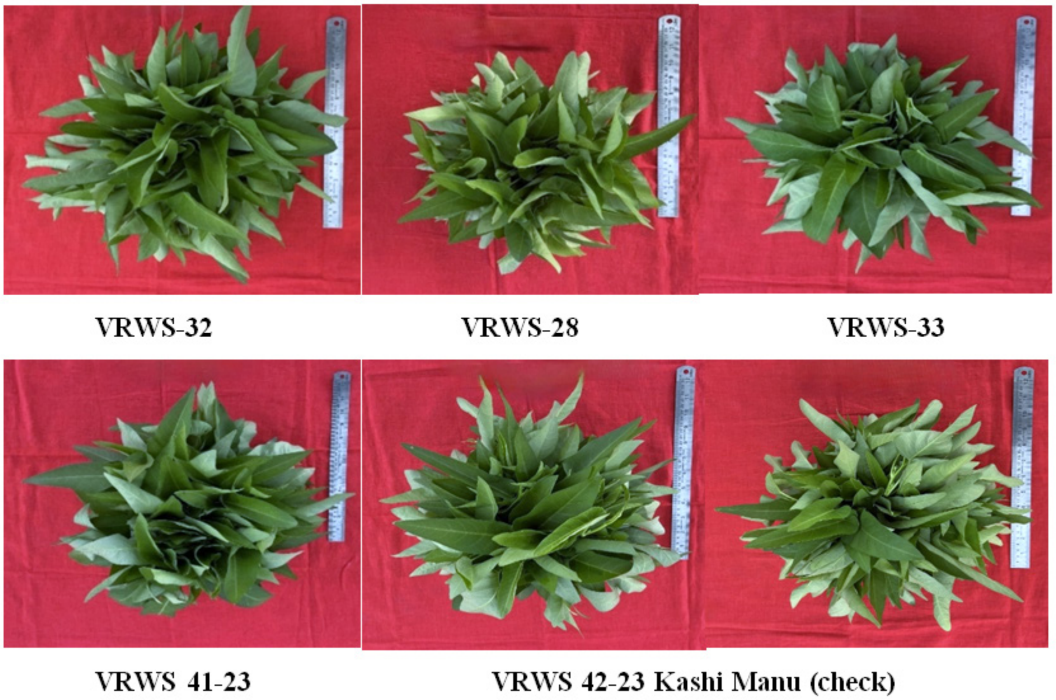


**Fig. 1:** Top five at par water spinach genotypes on mean performance with the check variety

VRWS 55-23 (4.90), VRWS 50-23 (4.86), VRWS-33 (4.71), VRWS 52-23 (4.64) and VRWS 56-23 (4.60) were observed statistically at par with check (4.72 cuttings). Previous studies by Sarker et al. (2014) reported that cutting frequency is influenced by environmental conditions, genetic traits and management practices like irrigation and fertilization. The leaf width ranged between 3.07 and 6.90 cm; the genotype VRWS 48-23 recorded the highest leaf width (6.90 cm), which was significantly superior to all other genotypes, including the check (6.05 cm). A group of genotypes VRWS 47-23 (6.64 cm), VRWS 49-23 (6.27cm), VRWS 50-23 (6.03cm), VRWS 51-23 (6.01 cm), VRWS 46-23 (5.97 cm), VRWS 42-23 (5.91 cm), VRWS 45-23 (5.75 cm), VRWS 43-23 (5.70 cm), VRWS 44-23 (5.59 cm), VRWS 52-23 (5.25 cm) and VRWS 40-23 (5.23 cm) were showed statistically at par with check. Genotypes with broader leaves are generally more effective at capturing light, which supports greater photosynthetic activity and thus, higher yield (Poorter et al., 2012). In the same crop, Snyder et al. (1981) reported 2 to 5 cm and Ekwealor et al. (2020) recorded 4.273 to 4.887 cm leaf width, which is similar to our findings. The petiole length showed notable variation, the genotype VRWS 51-23 noted the highest petiole length (5.96 cm) followed by VRWS 49-23 (5.93 cm), VRWS 50-23 (5.68 cm), VRWS 42-23 and VRWS 43-23 (both 5.60 cm), VRWS-33 and VRWS 41-23 (5.43 cm), VRWS57-23 (5.41cm), VRWS-32 (5.35 cm), VRWS 48-23 (5.34 cm), VRWS 46-23 (5.12 cm), VRWS 319 (5.02 cm), VRWS 45-23 (5.00 cm), VRWS-28 (4.95 cm), VRWS 44-23 and VRWS 52-23 (5.22 cm) were statistically at par with check (5.43 cm). These observations are consistent with the findings of Gebauer et al. (2016), who observed that petiole length positively contributes to better canopy structure and yield potential in leafy vegetables. The leaf length ranged from 6.99 cm to13.95cm where he genotype VRWS 46-23 recorded the highest leaf length (13.95 cm) followed by VRWS 41-23 (13.86 cm), VRWS 44-23 (13.44 cm), VRWS-32 (13.30 cm), VRWS-28 (13.30 cm), VRWS 47-23 (13.62 cm), VRWS 49-23 (13.57 cm), VRWS 48-23 (13.49 cm), VRWS 42-23 (13.21 cm), VRWS 45-23 (13.20 cm), VRWS 40-23 (12.25 cm), VRWS 43-23 (12.29 cm), VRWS 31 (12.66 cm), VRWS 51-23 (12.58 cm), VRWS-33 (12.04 cm), VRWS 50-23 (13.06 cm) and VRWS 52-23 (11.84 cm) were statistically at par with check. Gangopadhyay et al. (2021) described that leaf length is an important morphological trait in leafy vegetables, as it directly influences leaf area, photosynthetic capacity and marketable biomass. Snyder et al. (1981) reported 5 to 15 cm leaf length in water spinach, which supports our findings. Shorter intermodal length than check variety Kashi Manu was observed in genotypes VRWS 45-23 (2.78 cm), VRWS 43-23 (2.76 cm) and VRWS 46-23 (2.75 cm). Rana and Brar (2017) stated that water spinach has a hollow stem because of its hollow stem nature; genotypes with longer stems may be more prone to lodging, which might not be desirable for upland field cultivation. Genotypes that revealed internodal length significantly shorter than the check can be desirable for upland cultivation to obtain high leafy biomass production, as each node produces vines and leaves (Rana and Brar, 2017). Sarkar et al. (2014) reported 1.80 to 2.04 cm internodal length in water spinach, similar to some genotypes of the present study.


**Fig. 2:** Variability in flower and leaf characters in water spinach genotypes

The genotypes showed variation in leaf shape, arrowhead-shaped leaves in 16 genotypes, cordate-shaped leaves in 6 genotypes and hastate-shaped leaves in 5 genotypes (Table 2). Tiwari and Chandra (1985) observed sagittate leaves in the same crop. Snyder et al. (1981) described that the leaves ofwater spinach are long-stemmed, alternate and lanceolate to triangular, often hastate or heart-shaped at the base. The majority of genotypes (18) showed pure white flowers, while the rest of the 7 genotypes out of 25 exhibited flowers with a white border and a purple center. Snyder et al. (1981) have also mentioned that in water spinach, flower color can be typically white with magenta or purple throat, but sometimes entirely white, pink, purple/lavender, which supports current findings (Fig 2).

### *Genetic variability studies*

In the present investigation, estimates of genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability and genetic advance (GA) were estimated for morpho-metric traits of upland-grown

**Table 2:** Mean performance of water spinach genotypes for the traits leaf shape and flower colour

| *Genotypes* | *Leaf shape* | *Flower colour* |
|---|---|---|
| VRWS-32 | Arrow head | Pure white |
| VRWS-28 | Arrow head | Pure white |
| VRWS-33 | Arrow head | Pure white |
| VRWS-31 | Arrow head | Pure white |
| VRWS 40-23 | Hastate | Pure white |
| VRWS 41-23 | Arrow head | Pure white |
| VRWS 42-23 | Hastate | Pure white |
| VRWS 43-23 | Arrow head | Pure white |
| VRWS 44-23 | Arrow head | Pure white |
| VRWS 45-23 | Hastate | Pure white |
| VRWS 46-23 | Cordate | Pure white |
| VRWS 47-23 | Arrow head | Pure white |
| VRWS 48-23 | Arrow head | Pure white |
| VRWS 49-23 | Arrow head | Pure white |
| VRWS 50-23 | Cordate | Pure white |
| VRWS 51-23 | Cordate | Pure white |
| VRWS 52-23 | Cordate | Pure white |
| VRWS 54-23 | Arrow head | White boarder with purple centre |
| VRWS 55-23 | Arrow head | White boarder with purple centre |
| VRWS 53-23 | Cordate | White boarder with purple centre |
| VRWS -Red | Cordate | White boarder with purple centre |
| VRWS 56-23 | Hastate | White boarder with purple centre |
| VRWS 57-23 | Arrow head | Pure white |
| VRWS58-23 | Hastate | White boarder with purple centre |
| Kashi Manu (Check) | Arrow head | Pure white |

*Ipomoea aquatica* genotypes during 2023 and 2024. These parameters indicate the extent of genetic diversity and the relative contribution of genetic and environmental factors influencing trait expression (Table 3).

*Genotypic and phenotypic coefficients of variation*

The GCV and PCV values varied widely for different traits. High GCV was recorded for internodal length (23.43%), stem diameter at 30DAS (22.30%), leaf biomass yield/m²/month (22.49%) and yield/plant/month (21.23%), indicating substantial genetic variability. Moderate GCV was found for days to 50% germination (14.17%), number of vines/plant after 10 cuttings (14.15%), leaf length (13.83%) and leaf width (13.88%), while other traits showed low GCV. Similarly, PCV ranged from high in internodal length (24.16%) and biomass traits (22.28–22.49%) to low in stem diameter at 10DAS (6.54%). The close similarity between PCV and GCV for many traits indicates minimal environmental influence and strong genetic control. According to Johnson et al. (1955), such traits are unchanging and reliable for selection.

*Heritability*

Heritability ranged from moderate to high. The high values were noted for internodal length (94.05%), emergence of vines during first harvest (92.83%), days to 50% germination (91.40%) and biomass yield traits (>90%). Moderate heritability was observed for plant height at 20DAS (57.19%), days to first harvesting (53.12%) and number of nodes/plant (50.06%). High heritability recommends strong genetic determination and minimal environmental effects (Burton & DeVane, 1953), suggesting that phenotypic selection for such traits would be effective.

**Table 3:** Estimates of PCV, GCV, heritability and genetic advance for yield and its attributing traits in water spinach genotypes

| *Trait* | *GCV (%)* | *PCV (%)* | *h2 bs (%)* | *GA as % of mean* |
|---|---|---|---|---|
| Days to 50% germination | 14.17(M) | 14.82(M) | 91.40(H) | 27.92(H) |
| Plant height in 10 DAS | 4.6(L) | 7.63(L) | 36.40(M) | 5.72(L) |
| Plant height in 20 DAS | 6.38(L) | 8.44(L) | 57.19(M) | 9.95(L) |
| Plant height in 30 days (cm) | 8.22(L) | 8.83(L) | 86.58 (H) | 15.75(M) |
| Stem diameter in 10 DAS (mm) | 5.81(L) | 6.54(L) | 79.31(H) | 10.78(M) |
| Stem diameter in 30 DAS (mm) | 21.06(H) | 22.30(H) | 89.13(H) | 40.96(H) |
| Days to 1st harvesting | 5.17(L) | 7.09(L) | 53.12(M) | 7.76(L) |
| Yield per plant/month | 21.23(H) | 22.28(H) | 90.829(H) | 41.68(H) |
| Yield/m2/month | 21.42(H) | 22.49(H) | 90.71(H) | 42.03 (H) |
| Emergence of vines during harvesting | 6.93(L) | 7.19(L) | 92.83(H) | 15.14(M) |
| No. of vines/plant (after 10 cuttings) | 14.15(M) | 17.36(M) | 66.49(H) | 23.785(H) |
| No. of nodes/plant | 7.26(L) | 10.26(M) | 50.06(M) | 10.58(M) |
| No. of cuttings/month | 8.23(L) | 8.87(L) | 86.07(H) | 15.74(M) |
| Leaf width(cm) | 13.88(M) | 15.90(M) | 76.23(H) | 24.98(H) |
| Petiole length(cm) | 9.09(L) | 10.44(M) | 75.89(H) | 16.32(M) |
| Leaf length(cm) | 13.83(M) | 15.96(M) | 75.00(H) | 24.67(H) |
| Internodal length(cm) | 23.43(H) | 24.16(H) | 94.05(H) | 46.81(H) |

*Genetic advance*

Genetic advance as a percent of average ranged from 5.72% (plant height at 10DAS) to 46.81% (internodal length). High GA was also observed for stem diameter at 30 DAS (40.96%), leaf biomass yield/m$^2$/month (42.03%) and yield/plant/month (41.68%) and days to 50% germination (27.92%). These traits with high heritability and GA specify predominance of additive gene action and so, direct selection would be effective (Johanson et al., 1955). Traits such as plant height at 10 DAS showed low GA despite moderate heritability, showing non-additive gene effects and environmental influence that may require hybridization/recurrent selection (Burton & DeVane, 1953). Moderate heritability and GA for plant height at 30DAS, stem diameter (30 DAS) and biomass yield traits propose additive gene action with moderate environmental influence (Guleria et al., 2009).

## Conclusion

The study revealed significant genotypic variation among water spinach genotypes for all growth and yield-related traits under upland conditions, confirming the existence of plenty of genetic diversity. High heritability and genetic advance for traits such as internodal length, stem diameter and leaf biomass yield suggest that these are primarily governed by additive gene effects and therefore, direct phenotypic selection would be effective for their improvement. Genotypes like VRWS-32, VRWS-28, VRWS-33, VRWS 41-23 and VRWS 42-23 established superior performance and stability, making them promising genotypes for selection and future breeding programs. Overall, the results highlighted that systematic selection strategies targeting highly heritable and yield-attributing traits can effectively enhance the productivity and adaptability of water spinach in upland cultivation systems.

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## सारांश

वर्तमान अध्ययन जिसका शीर्षक “ऊपरी भूमि परिस्थितियों में कलमी साग (*Ipomoea aquatica* Forssk.) जनन्द्रव्य में आनुवंशिक विविधता और उपज सुधार हेतु चयन रणनीतियाँ” है, वर्ष 2023-2024 के दौरान सम्पादित किया गया। इसका उद्देश्य कलमी साग की उपलब्ध संख्या में आनुवंशिक विविधता की सीमा का आकलन करना तथा उपज एवं वृद्धि से सम्बंधित गुणों के आधार पर संभावित श्रेष्ठ जनन्द्रव्य की पहचान करना था। कुल 25 जननियों (जिनमें जाँच किस्म ‘काशी मनु’ भी सम्मिलित थी) का मूल्यांकन तीन पुनरावृत्तियों सहित रैण्डमाइज़्ड ब्लॉक डिज़ाइन में किया गया। विभेदन विश्लेषण (ANOVA) से सभी परीक्षण किए गए गुणों में जननियों के बीच अत्यंत महत्वपूर्ण अंतर प्राप्त हुए, जो पर्याप्त आनुवंशिक विविधता की उपस्थिति को दर्शाते हैं । प्रमुख गुणों जैसे 50% अंकुरण के दिन (2.39–4.56 दिन), 30 DAS पर पौधे की ऊँचाई (43.50–69.90 से.मी.), 30 DAS पर तने का व्यास (6.54–10.76 मि.मी.) तथा प्रति पौधा प्रति माह पत्ती जैव-भार उपज (0.67–1.68 कि.ग्रा.) में व्यापक परिवर्तनशीलता दर्ज की गई । इंटरनोड़ की लंबाई, तने का व्यास (30 DAS) एवं बायोमास उपज जैसे गुणों में उच्च वंशानुगतता (heritability) के साथ उच्च आनुवंशिक प्रगति (genetic advance) प्राप्त हुई, जो प्रमुखतः उपस्थापक (additive) जीन क्रिया को दर्शाती है और प्रत्यक्ष चयन को प्रभावी बनाती है । जनन्द्रव्य VRWS-32, VRWS-28, VRWS-33, VRWS 41-23 तथा VRWS 42-23 ने उत्कृष्ट उपज प्रदर्शन दिखाया, जो चेक किस्म के बराबर या उससे बेहतर था। इन परिणामों से स्पष्ट होता है कि परीक्षण किए गए जर्मप्लाज्म में पर्याप्त आनुवंशिक क्षमता विद्यमान है तथा ऊपरी भूमि परिस्थितियों के लिए उच्च उपज देने वाली श्रेष्ठ कलमी साग किस्मों के विकास हेतु चयन आधारित सुधार की व्यापक संभावनाएँ मौजूद हैं ।