Research Article

Effect of sodium polyacrylate (Hydrogel) on growth and flowering of petunia

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Abstract

This study evaluates the separate and combined effects of sodium polyacrylate (hydrogel) and irrigation schedules on the growth and flowering of Petunia plants. Water stress is a major abiotic factor that negatively affects flower morphology and the production of high-quality blooms by disrupting plant growth, physiological processes, and metabolic functions. An experimental study was conducted using different sodium polyacrylate treatments (SP0: pure soil; SP1: 90% soil, 10% sodium polyacrylate; SP2: 70% soil, 30% sodium polyacrylate; SP3: 50% soil, 50% sodium polyacrylate) combined with varying irrigation intervals (W0: twice daily; W1: daily; W2: every other day; W3: every third day) to assess their effects on vegetative and reproductive attributes of Petunia. The results indicated that SP2 (70% soil + 30% sodium polyacrylate) significantly reduced the time to flowering and increased both the quantity and size of flowers, while SP1 (90% soil + 10% sodium polyacrylate) enhanced vegetative growth, including the number of leaves, branches, plant height, root length, and root volume. Irrigation every three days promoted earlier flowering and improved floral traits, whereas irrigation at two-day intervals favored vegetative growth. Interactive effects of sodium polyacrylate and irrigation schedules significantly influenced both morphological and floral characteristics. Based on these findings, SP2 with a three-day irrigation interval is recommended for reproductive performance, and SP1 with a two-day interval is recommended for vegetative growth of Petunia.

Keywords: Abiotic Stress, Sodium Polyacrylate, Hydrogels, Water Holding Capacity, Percolation.

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Introduction

Changing climatic patterns and high demand for water in industrial and domestic sectors have created increasing pressure to minimize water application to ornamental plants [1]. With a growing global population, improving water-use efficiency in agricultural setups has become critical. Drought stress is one of the most important abiotic factors negatively affecting plant growth, flowering, and overall productivity.

Bedding plants are a popular feature in the urban landscape, widely used in public parks, town centers, and private gardens, both as planted plants and in containers and hanging baskets. Given changing climatic patterns and increased demand for water for domestic and industrial use [1], local authorities face pressure to minimize irrigation for ornamental plants. As a result, bedding plants are being replaced in many landscapes by more xerophytic but often less colorful species, many of which rely on foliage rather than flowers for their display [2].

Drought stress remains the most important limiting environmental factor for plant growth [3]. Water deficit stress is one of the leading limitations to photosynthesis and plant primary productivity [4]. For this reason, timely evaluation of plant water status through physiological measurement sensors, including canopy temperature/reflectance, sap flow, and stem variation, has proven useful in irrigation control [5].

Water is a key component of plant growth and production. Although water is present in the soil, it is lost downward through percolation, with the rate depending on soil type. Adding polymers to the soil can reduce this percolation and improve water availability to plant roots.

Super absorbent polymers were first used commercially in the 1970s, and by 1978 Park Davis had introduced them into sanitary napkins. Europe adopted them in baby diapers in 1982, and continued research and development in this area eventually led to the production of ultra-thin diapers. These polymers are sold under various names, including root watering crystals, drought crystals, and super absorbent polymers, and are commonly referred to as hydrogels. Available as crystals or small beads, hydrogels have a large capacity to retain water and release it gradually to plants as needed [6 - 8].

Adding polymers to soil increases the bonding force between particles, making them easier to disperse and forming larger aggregate structures. In particular, the proportion of aggregates larger than 1 mm increases rapidly. Polymer addition also improves plant rooting and growth, which in turn enhances crop quality and yield [9]. These materials can retain organic matter in the soil and adapt well to environments with alternating wet and dry conditions [10 - 11]. Hydrogel accumulation further improves water retention in soil and delays the onset of permanent wilting point under high evaporation conditions [12].

In ornamental crop production, good watering practice is important for reducing nutrient leaching from the soil [13 - 14]. Previous studies have shown that hydrogels perform well under partial water deficit conditions [8]. Plant roots are able to extract water directly from the crystal beads and chains of hydrogel structures [7]. Hydrogels also improve soil physico-chemical properties, including structural stability, water holding capacity, and overall soil productivity [15 - 16].

Good irrigation management is an important best management practice in ornamental crop production, as it reduces runoff of nutrient and pesticide-rich water from production sites [13 - 14, 17]. Better irrigation control also offers additional benefits, including improved plant quality, more compact growth [18], and reduced damage from root pathogens [19]. To address these issues, an experimental study was planned to evaluate the response of sodium polyacrylate on morphological and flowering attributes of petunia plants, with the following objectives: (i) to investigate the effect of different concentrations of sodium polyacrylate on quality flower production of petunia under stress conditions, and (ii) to determine the best irrigation interval for producing quality flowers.

Materials and Methods

Experimental site and design

An experiment entitled "Effect of sodium polyacrylate (hydrogel) on growth and quality flower production of Petunia under water stress" was conducted at the Ornamental Nursery, Department of Horticulture, The University of Agriculture Peshawar (34°01'22.1" N, 71°28'43.0" E) during winter 2019. Peshawar is a subtropical city situated at 350 m above sea level (latitude 34.01°N, longitude 71.35°E), located 1600 km north of the Indian Ocean [20 - 22]. The Indus River enters the valley from the northwest, fed by a number of smaller water bodies [23]. The soil of Peshawar is generally a mixture of clays, silts, boulders, gravels, and pebbles [23]. As a subtropical zone, temperatures range from a severe winter low of 5°C to a peak summer high of 45°C, with June being the hottest month (rainfall 7 mm) and March the wettest (rainfall 78 mm) [24 - 25].

A Completely Randomized Design (CRD) with two factors and three replications was used. Treatments included four levels of sodium polyacrylate (SP): SP0 (soil without sodium polyacrylate), SP1 (90% soil + 10% sodium polyacrylate), SP2 (70% soil + 30% sodium polyacrylate), and SP3 (50% soil + 50% sodium polyacrylate); and four irrigation intervals: W0 (half-day), W1 (1-day), W2 (2-day), and W3 (3-day).

Dry baby diapers were soaked in water for 10 minutes to allow the hydrogel to swell. The hydrogel was carefully extracted and mixed into the soil at the designated concentrations. The soil mixture consisted of garden soil, silt, and leaf mold in a 1:1:1 ratio. Petunia seedlings were then transplanted into individual pots containing the prepared soil-hydrogel mixtures [26].

Note: The sodium polyacrylate was obtained from commercially available baby diapers, which may contain small amounts of other substances. This method was adopted for practical and exploratory purposes.

Data collection

Morphological and floral attributes were recorded. Number of leaves and branches per plant were counted for five randomly selected plants per replication and average. Plant height was measured from soil surface to the highest tip using a measuring tape. Days to first flowering were recorded from the date of transplanting. Flowers were counted every third day from first bloom until senescence, and flower size was measured using a ruler. Root length was measured from the base to the tip, and root volume was determined using the water displacement method for five randomly selected plants per replication.

Statistical analysis

Data was analyzed using Analysis of Variance (ANOVA) through Statistix 8.1 software (Tallassee, FL, USA), appropriate for a Completely Randomized Design. Mean comparisons were made using the Least Significant Difference (LSD) test at $P \leq 0.05$ [27].

Results

Days to flowering

It is obvious from Table 1 that Sodium polyacrylate and irrigation interval significantly influenced days to flowering of petunia. The early flowering (11.58) was recorded in SP_2 (70% soil + 30% sodium polyacrylate), while more days (14.33) were observed in plant received 50% sodium polyacrylate + 50% soil medium. Regarding irrigation interval, Petunia plant received irrigation after 3 days' interval produced earlier flowering (11.25), whereas maximum days to flowering (15.58) was recorded in a half-day irrigation interval. (Table 1).

Number of leaves plant^{-1}

The statistical analysis of data revealed that number of leaves plant^{-1} was significantly influenced by sodium polyacrylate, irrigation interval and their interactions (Table 1). The maximum number of leaves plant^{-1} (42) were recorded in plants supplied with 10% of sodium polyacrylate, while lowest value of number of leaves plant^{-1} (24) was recorded in plant received 50% of sodium polyacrylate with soil medium. Similarly, maximum number of leaves (46) were noticed in irrigation intervals of 2 days compared to number of leaves (29) observed in half days' irrigation interval, respectively (Table 1). The interaction between sodium polyacrylate and irrigation interval revealed that maximum number of leaves (55) was observed in SP_1 (90% soil + 10% sodium polyacrylate) and irrigated after 2 days' interval. While plant treated with 50% of sodium polyacrylate + 50% soil and irrigated twice a day produced number of leaves plant^{-1} (19.67) Figure 1).

Number of branches plant^{-1}

Number of branches of petunia significantly influenced by sodium polyacrylate, irrigation interval and their interaction (Table 1). The highest number of branches (4.58) was recorded in SP_1 (90% soil + 10% sodium polyacrylate), while lowest number of branches plant^{-1} (3.75) was observed in SP_3 (50% soil + 50% sodium polyacrylate). Regarding irrigation interval, plant irrigated with 2 days' interval attained maximum number of branches plant^{-1} (4.83), whereas minimum number of branches (3.25) were recorded in irrigation interval of half day (Table 1). The interaction between sodium polyacrylate and irrigation interval revealed that maximum number of branches (5.33) was observed in SP_1 (90% soil + 10% sodium polyacrylate) and irrigated after 2 days compared to SP_3 (50% soil + 50% sodium polyacrylate) and irrigated twice a day produced minimum number of branches plant^{-1} (2.33). (Figure 1).

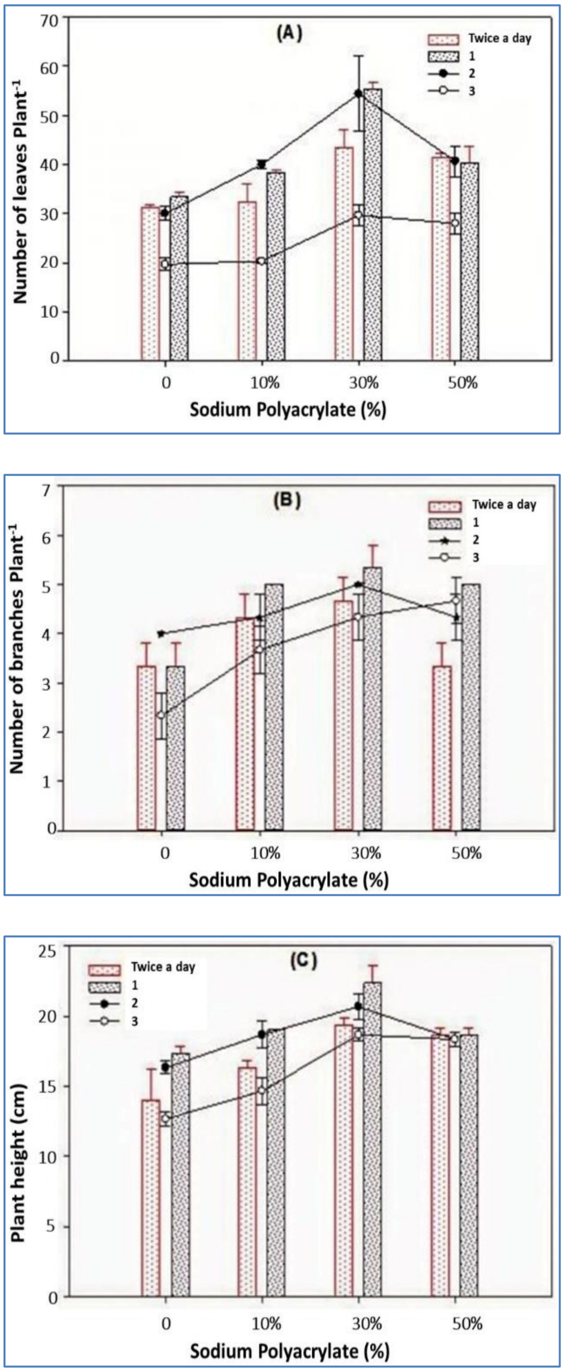


Figure 1 (A - C): Growth and flower production related traits of petunia as influenced by interaction of sodium polyacrylate and irrigation interval.

Plant height (cm)

It is obvious from Table 1 that there are highly significant differences between the treatments and their interaction. The highest value of plant height (19.33cm) was recorded in SP_1 (90% soil + 10% sodium polyacrylate), while lowest value of plant height (16.08 cm) was observed in SP_3 (50% soil + 50% sodium polyacrylate). Regarding irrigation interval, taller plant (20.25 cm) was observed in petunia plant irrigated with 2 days' interval, whereas minimum plant height (15.08cm) was observed by half day irrigation interval (Table 1). The interaction between sodium polyacrylate and irrigation interval revealed that maximum value of plant height (22.33cm) was observed in SP_1 (90% soil + 10% sodium polyacrylate) with irrigation interval of 2 days as compared to plant height (12.67cm) observed in petunia plant treated with 50% of sodium polyacrylate + 50% soil and irrigated twice a day (Figure 1).

Number of flowers plant^{-1}

Data presented in Table 1 indicated that sodium polyacrylate, irrigation interval and the interaction of both significantly influenced the number of flowers per plant. Among the different concentrations of sodium polyacrylate, maximum number of flowers (16) was recorded in using SP_2 (70% soil + 30% sodium polyacrylate) compared to SP_3 (50% soil + 50% sodium polyacrylate that produced minimum number of flowers plant^{-1} (12). Similarly, in different irrigation intervals, highest number of flowers plant^{-1} (17) were recorded in irrigation after 3 days, while minimum number of flowers plant^{-1} (7) were observed in half day interval (Table 1). The interaction between sodium polyacrylate and irrigation interval revealed that maximum value of number of flowers plant^{-1} (21.33) was observed in using 30% of sodium polyacrylate + 90% soil with irrigation interval of 3 days, while minimum number of flowers plant^{-1} (7.33) treated with 50% of sodium polyacrylate + 50% soil and irrigated twice a day (Figure 2).

Flower size (cm)

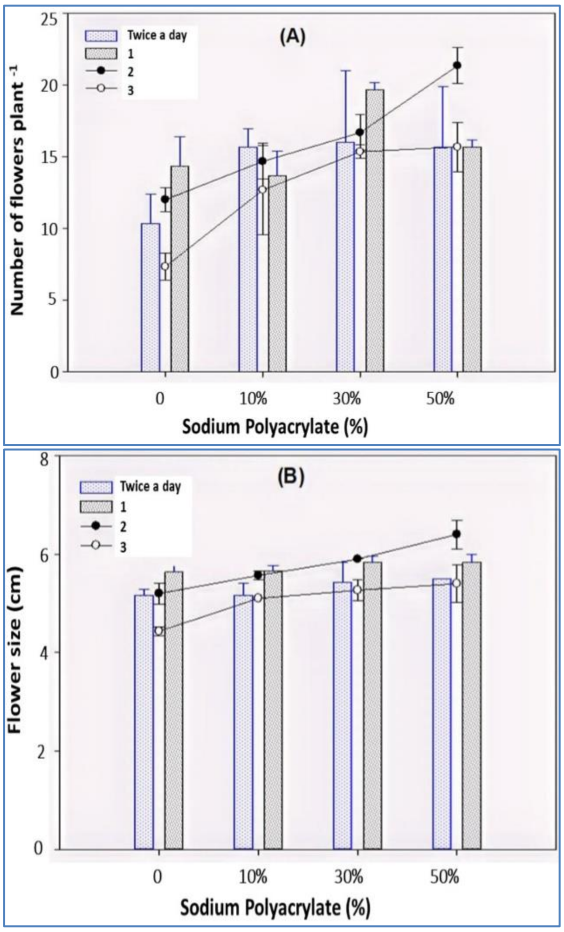
The analysis of variance revealed highly significant differences among the treatments and their interaction (Table 1.). The highest value of flower size (5.77cm) was recorded in SP_1 (90% soil + 10% sodium polyacrylate), while lowest value of flower size (5.05 cm) was observed in plant received (50% of sodium polyacrylate + 50% soil medium). Irrigation interval after 3 days showed maximum flower size (5.78 cm), whereas minimum flower size (5.11 cm) was recorded by half day irrigation interval, (Table 1).

Table 1: Growth and flower production related traits of petunia as influenced by sodium polyacrylate and irrigation intervals.

Treatments	Days to flowering	No. of leaves plant^{-1}	No. of leaves plant^{-1}	Plant height (cm)	No. of flowers plant^{-1}	Flower size (cm)	Root length (cm)	Root volume (ml)
Sodium polyacrylate (S.P) (%)								
Control	14.00ab	37.08b	3.92b	17.08bc	13.58bc	5.32b	9.00b	0.88b
10	13.00b	41.83a	4.58a	19.33a	15.83ab	5.74a	10.42a	1.14a
20	11.58c	41.25a	4.42a	18.50ab	16.17a	5.77a	10.08a	1.09a
30	14.33a	24.42c	3.75b	16.08c	12.67c	5.05b	7.17c	0.79b
LSD≤0.05	0.84	2.82	0.43	0.89	1.70	0.20	0.81	0.06
Irrigation intervals (I.I) (days)								
Twice a day	15.58ab	28.58	3.25	15.08c	11.00c	5.11c	7.5	0.84c
1	13.58b	32.75c	4.25	17.17b	14.08b	5.38	8.92b	0.95bc
2	12.50c	45.67a	4.83	20.25a	16.08b	5.61	10.25a	1.10a
3	11.25a	37.58b	4.33	18.50b	17.08	5.78a	10.00a	1.01ab
LSD≤0.05	0.84	2.82	0.43	0.89	1.70	0.20	0.81	0.06
Interaction								
S.P×I.I	NS	Figure 1	Figure 1	Figure 1	Figure 2	Figure 2	Figure 2	Figure 2

Root length (cm)

The analysis of data showed that root length was significantly influenced by sodium polyacrylate, irrigation interval and their interactions (Table 1). Among the different concentrations, longer root (10.42) was observed SP_1 (90% soil + 10% sodium polyacrylate), while minimum root length (7.17cm) was noticed in SP_1 (50% soil + 50% sodium polyacrylate). Regarding irrigation, maximum root length (10.25 cm) was observed by applying irrigation after 2 days, while minimum root length (7.50 cm) was recorded by applying irrigation twice a day (Table 1). The interaction between sodium polyacrylate and irrigation interval revealed that maximum length of root (12 cm) was observed in using 10% of sodium polyacrylate + 90% soil with irrigation interval of 2 days compared to plant treated with 50% of sodium polyacrylate + 50% soil and irrigated twice a day attained minimum root length (4.33cm) (Fıgure 2).



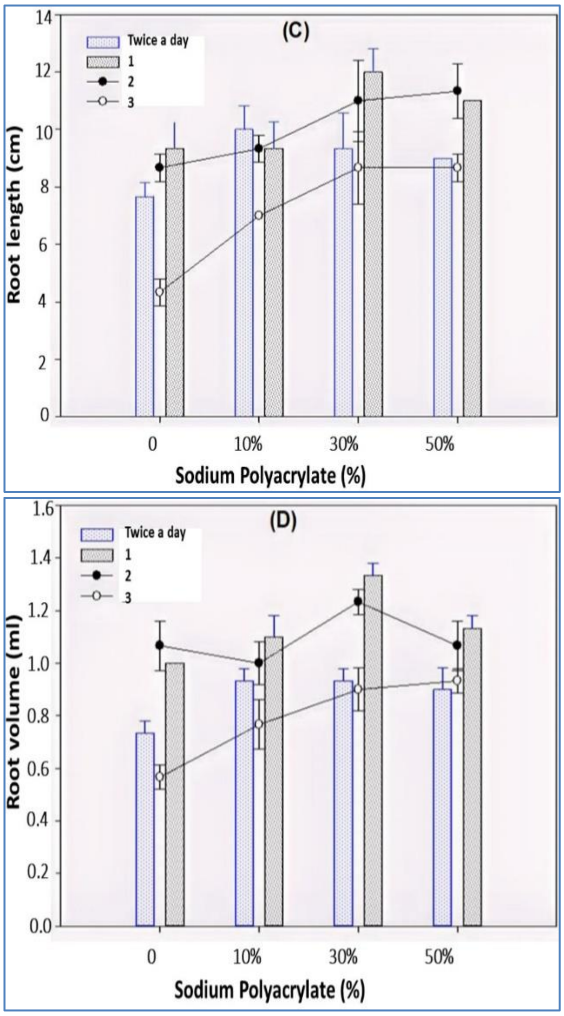


Figure 2 (A - D): Growth and flower production related traits of petunia as influenced by interaction of sodium polyacrylate and irrigation interval.

Root volume (ml)

The analysis of data showed that root volume was significantly influenced by sodium polyacrylate, irrigation and interactions of both (Table 1). Among the different concentrations, maximum root volume (1.14 ml), was observed in SP_1 (90% soil + 10% sodium polyacrylate), while minimum root length (0.97 ml) was noticed in SP_3 (50% soil + 50% sodium polyacrylate). Regarding irrigation, maximum root length (1.10 ml) was observed by applying irrigation after 2 days, while minimum root length (0.84 ml) was recorded by applying irrigation twice a day (Table 1). The interaction between sodium polyacrylate and irrigation interval revealed that maximum root volume (1.33ml) was observed in using 10% of sodium polyacrylate + 90% soil with irrigation interval of 2 days compared to plant treated with 50% of sodium polyacrylate + 50% soil and irrigated twice a day attained minimum root length (0.57ml) (Fıgure 2).

Correlation and principal component analysis of different attributes of petunia

The Pearson correlation was calculated among different attributes of petunia. A significant correlation was found to be at the attributes (Fig 3). The positive correlation was recorded in NL vs. NB (0.6027), NL vs. PH (0.7776), NB vs. PH (0.7124), NL vs. NF (0.5502), NB vs. NF (0.5315), PH vs. NF (0.6069), NL vs. FS (0.6418), NB vs. FS (0.5917), PH vs. FS (0.6046), NF vs. FS (0.6030), NL vs. RL (0.7626), NB vs. RL (0.6566), PH vs. RL (0.6930), NF vs. RL (0.7032), FS vs. RL (0.7326), NL vs. RV (0.7535), NB vs. RV (0.6928), PH vs. RV (0.7679), NF vs. RV (0.5263), FS vs. RV (0.6878), and RL vs. RV (0.7942).DF shows negative correlations with all the attributes studied.

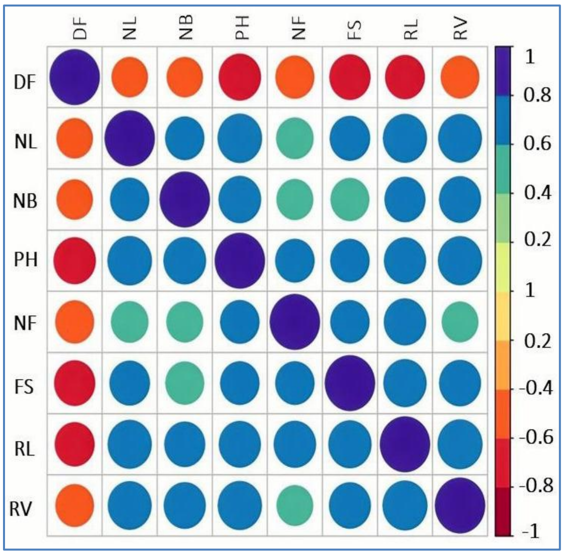


Figure 3: Correlation of different attributes of petunia .*DF* Days to flowering, *NL* No. of leaves plant^{-1},*NB* No. of Branches plant^{-1}, *PH* Plant height ,*NF* No. of flowers plant^{-1}, *FS* Flower size, *RL* Root length, *RV* Root volume.

The Principal component analysis was calculated by using the mean values of the attributes (Fig 4). According to the scree plot the highest contribution was recorded in PC1 (69.6%), PC2 (7.8%) and PC3 (5.80%) covered about 83% of the total variance.

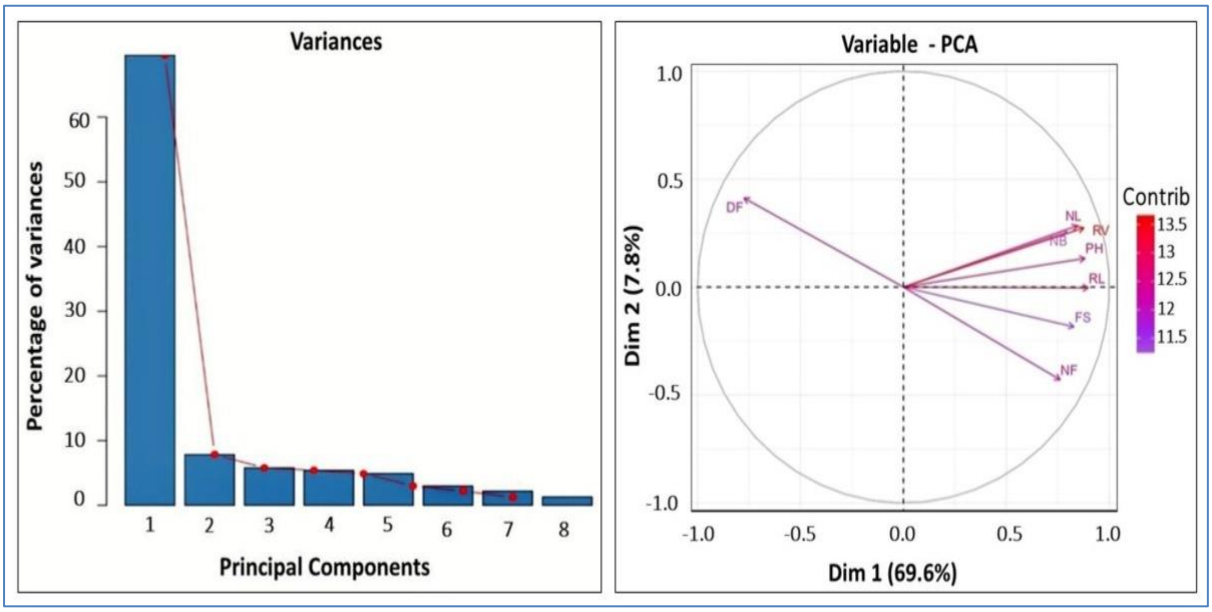


Figure 4: Eigen values for different attributes of petunia and principal component analysis of different attributes of petunia .*DF* Days to flowering, *NL* No. of leaves plant^{-1},*NB* No. of Branches plant^{-1}, *PH* Plant height ,*NF* No. of flowers plant^{-1}, *FS* Flower size, *RL* Root length, *RV* Root volume.

Discussion

Days to flowering

Early flower initiation at the 3-day irrigation interval may be due to water stress shifting the plant from vegetative to reproductive growth, triggering earlier flower production. Similar findings were reported by Kiyoshi [28], who noted that plants switch from vegetative to reproductive growth under stress conditions. In contrast, higher concentrations of sodium polyacrylate promoted greater vegetative growth, likely because the hydrogel retained more water, keeping plants in a vegetative state for longer.

The role of water stress in flower production has also been examined [29], showing that the number of flowers produced by Matricaria chamomile decreased with longer irrigation intervals. Similar effects of water stress on productivity have been observed in field crops, where it was reported [30] that water deficit greatly reduced crop productivity, particularly when it occurred at the flowering stage.

Number of leaves plant^{-1}

The maximum number of leaves per plant may be attributed to sufficient soil moisture availability, which allowed plants to absorb more nutrients from the soil, supporting greater growth and higher leaf production. Similar results have been observed previously [31]. Mixing 30% sodium polyacrylate into the soil produced the best results, which may be because as the surrounding soil in the root zone begins to dry, the hydrogel releases stored water and nutrients directly to plant roots. These findings are consistent with reports [32] that hydrogel polymer application to soil improved water accessibility in the substrate, increased leaf chlorophyll and leaf water content, promoted plant growth, reduced nutrient leaching, and improved soil penetration. The interaction of 30% sodium polyacrylate with a 2-day irrigation interval also showed the best results, likely due to sufficient water availability meeting the specific irrigation requirements of the plant.

Number of branches plant^{-1}

The maximum number of branches per plant may be attributed to sufficient soil moisture, which allowed plants to absorb more nutrients from the soil, supporting greater branching. Similar findings have been reported [33], noting that the number of branches was significantly affected by irrigation. Mixing 30% sodium polyacrylate into the soil produced the best results, likely due to the water retention properties of the hydrogel component. The present study confirmed that hydrogel application had a significant impact on improving the number of branches per plant [34]. These findings are consistent with previous reports [35], which showed that hydrogel application combined with controlled water stress enhanced branching and leaf number in tomato crops. As the soil around the root zone begins to dry, the hydrogel releases stored water and nutrients to the plant, supporting growth and prolonging plant survival under drought conditions [36].

Plant height (cm)

Maximum plant height may be attributed to greater water availability provided by sodium polyacrylate, which retains water in the soil and keeps plants in vegetative growth. Water availability directly affects plant height, as higher transpiration from larger leaf surface areas increases water loss [37]. Maximum plant height was observed at the 2-day irrigation interval combined with 10% sodium polyacrylate mixed into the soil, likely due to sufficient water availability at this level. Hydrogel improves water use efficiency, reduces irrigation costs, extends irrigation intervals, improves soil water holding capacity and porosity, and provides plants with steady moisture and nutrients, which supports root development, plant viability, and ultimately crop yield. Similar findings have been reported [35], showing that cucumber plants grown in hydrogel reached greater heights of 180 cm and 158 cm. In contrast, the 50% sodium polyacrylate treatment produced shorter plants, which may be due to excessive moisture causing depletion of available nutrients, consistent with reported findings [38] that plants attain less height under conditions of competition for moisture, space, and nutrients. The reduction in plant height at higher hydrogel concentrations may also be linked to reduced cell elongation, which lowers cell turgidity and volume and ultimately limits cell growth.

Number of flowers plant^{-1}

Maximum number of flowers per plant may be attributed to adequate water availability at the right irrigation interval. Higher irrigation frequencies, such as watering once or twice daily, kept the soil constantly wet, reducing oxygen availability in the spaces between soil particles and ultimately suppressing plant growth and flower production. The use of 30% sodium polyacrylate produced the maximum flowering yield, likely due to the water retention properties of the hydrogel maintaining optimal moisture levels around the root zone. Similar findings have been reported [34], showing that hydrogel-supplemented soil improved grain yield in wheat by up to 51%.

Flower size (cm)

The interaction between sodium polyacrylate and irrigation interval showed that the maximum flower size (6.40 cm) was recorded in plants treated with 30% sodium polyacrylate + 70% soil at a 3-day irrigation interval, while the minimum flower size (4.43 cm) was observed in plants treated with 50% sodium polyacrylate + 50% soil irrigated twice daily (Figure 2). Maximum flower size may be attributed to sufficient water availability, as plants absorb nutrients from the soil through water, and adequate nutrient uptake supports larger flower development. Similar findings have been reported [39], noting that nutrients are transported to plants through water. In contrast, the 50% sodium polyacrylate treatment, despite retaining more water, reduced oxygen availability to the roots due to excessive moisture, which directly affected plant growth and flower size. Consistent with this, reports [40] show that chrysanthemum seedlings grown in soil mixed with hydrogel at 0.5% wt/wt showed increased flower size and flower number compared to control treatments.

Root length (cm)

Maximum root length was recorded at the 2-day irrigation interval, which may be due to sufficient water availability to the roots of petunia plants. Similar results were reported [41], who stated that efficient irrigation management not only preserves soil moisture but also promotes root growth, plant growth, and overall plant quality in commercial production. Plants grown in 50% sodium polyacrylate retained more water but showed minimum root length when irrigated twice daily, which may be attributed to excessive moisture. Consistent with this, excess irrigation can limit or restrict root growth due to reduced oxygen diffusion rates, while insufficient irrigation can also reduce root growth and development due to water deficit or high soil strength [42].

Hydrogel particles act as miniature water reservoirs in the soil, releasing water to plant roots through osmotic pressure differences as needed. As the hydrogel releases water and its volume decreases, it creates free pore spaces in the soil, improving air and water infiltration, storage capacity, and conditions for root growth

[43].

Root volume (ml)

Maximum root volume at the 2-day irrigation interval may be attributed to adequate and timely water availability to the roots of petunia plants. Similar results were reported [44], who found that increasing irrigation rate had a significant effect on root system volume and density, along with other root characteristics associated with plant yield. The minimum root volume recorded at 50% sodium polyacrylate may be due to excessive water retention at that concentration, as higher hydrogel content retains more water than the plant requires, which can restrict root development. Similar findings were reported by Ghasemi and Khushkhui, who observed that roots, shoots, and flowers of chrysanthemum were enhanced by hydrogel application in soil under drought stress. Hydrogel use has also been shown to improve seed germination, plant viability, soil ventilation, and root development, particularly in arid environments, with notable increases in overall plant growth recorded when hydrogel is applied to the soil [45].

Conclusion

Sodium polyacrylate is a cross-linked hydrophilic polymer that can swell up in water to hundreds of times its dry weight. The effectiveness of hydrophilic polymers in enhancing soil water retention or in increasing yield is dependent on formulation and soil type. Our results indicated that quality flower production was recorded in SP_1 (10% sodium polyacrylate and 90% soil substrates). While reproductive growth (flower number, size) shows best results by the use of 10% sodium polyacrylate mixed with 90% soil from the rest of the treatments. Increasing irrigation interval significantly reduced quality of petunia flower and other morphological attributes.

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