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Growth Behavior of *Parthenium hysterophorus* as Influenced by Environmental Factors

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Authors' contributions

This work was carried out in collaboration among all authors. Authors SM and SS conceptualization and designed the study. Authors SM, Pooja and Meenu performed the statistical analysis, and wrote the first draft of the manuscript. Authors Radheshyam and SRP curation of data, editing of manuscript and finalizing the draft. All authors read and approved the final manuscript.

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ABSTRACT

Parthenium hysterophorus is a prime noxious weed across the world and resorting its nativity weed to Tropical North and South America which has invaded more than 50 countries throughout the world. It was accidentally introduced in India with food-grains imported from Mexico. Parthenium plant contains chemicals, like parthenin, hysterin, hymenin, and ambrosin, and due to the presence of these chemicals, the weed exerts strong allelopathic effects on different crops. Parthenin has been reported as a germination inhibitor as well as radical growth inhibitor in a variety of dicot and monocot plants. Because of its strong competitiveness for soil moisture, space and nutrients with crops and its allergenic properties, it poses serious threat to cereal crops and livestock. Parthenium is difficult to control because of its wider adaptation to diverse climatic conditions. The aim of this research article is to explore effect of environmental factors on germination, shoot and root length

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of *Parthenium hysterophorus.* The effect of light periods, temperature, pH, osmotic potential and salt stress on germination, shoot and root length of parthenium was studied and found that maximum germination at 16 h (57%), 25°C (81%), pH 7 (98%), 0 MPa (85%) and 0 mM NaCl (84%), respectively and same trend was followed in shoot and root length. Therefore, the understanding of growth behavior of parthenium will help in formulating better management practices for the same.

Keywords: Parthenium hysterophorus; photoperiod; temperature; pH; osmotic potential and salt stress.

1. INTRODUCTION

The effect of various environmental factors and growth behavior of a weed is important in understanding its competition with other plant species including crops. The knowledge of weed biology and weed ecology is therefore, essential to maximize the effectiveness of agronomic practices in the management strategy. Parthenium (*Parthenium hysterophorus* L.), commonly known as congress grass or carrot grass, is an invasive plant in India, accidentally introduced with food-grains introduced from Mexico and was first noticed in Pune in 1955 [1]. It is a native weed of Tropical North and South America (Mexico, USA) belonging to family Asteraceae and commonly called famine weed due to its ability to affect cereal crops and cattle livestock. It is an annual herb with a deep tap root and an erect multi-branch main stem which reaches up to height of 2 meters and has numerous bunches of flowers on the top. Due to its resemblance like carrot, it is also known as carrot grass. Seeds maturation occurs within two weeks of flowering. Plant completes its one generation within 15 to 18 weeks and may complete 4 to 5 overlapping generations in a year depending on the climatic conditions of the area.

Parthenium can grow in a wide range of soil types ranging from sandy to heavy clays, but favors the latter [2]. It has a great temperature tolerance and can grow in areas having temperatures between 10°C and 25°C. It has high germination ability throughout the year. The growth of Parthenium weed is restricted in saline and water-logged soils [3]. Parthenium plant contains numerous hazardous chemicals, like parthenin, hysterin, hymenin, and ambrosin. Presence of these chemicals causes allelopathic effects on nearby growing crops. It is also a notorious weed because of its strong competitiveness for soil moisture, space and nutrients with crops and its allergenic properties. Parthenium has better tolerance to drought, temperature variation, sunlight duration and its seeds don't undergo dormancy. All these characteristics make difficult to control Parthenium spread. All these characteristics make Parthenium an aggressive and prolific weed under non-cropped situations, and it is becoming a curse by overtaking social forestry, local pastures, and any or all open spaces including residential areas and its recent entry in crops is alarming.

Seed dormancy has not been noticed in Parthenium and the seeds normally germinate with the availability of moisture and can tolerate adverse climatic conditions better if seeds remain buried under the soil. It has been concluded that Parthenium seeds may survive between 4 to 6 years [4]. In the last six decades, this weed has covered the length and breadth of country causing an ecological disaster. In India, Parthenium weed is widely spread and infest about 2 million hectares of land [5] and can reduce crop yield by 40% and forage production up to 90% [6].

1.1 Rationale and Objectives of the Study

The weed is difficult to control because of its wider adaptation across climatic conditions, its photo- and thermo-insensitivity, drought tolerance, no seed dormancy and huge seed production capacity (10,000-15,000 seeds/plant). The knowledge of weed biology and weed ecology is therefore, essential to maximize the effectiveness of agronomic practices in the management strategy. Therefore, a study was conducted to ascertain effect of varied environmental factors viz., light periods, temperature, pH, osmotic potential and salt stress on the germination, shoot and root length of *Parthenium hysterophorus.*

2. MATERIALS AND METHODS

In the present study, 5 different treatments were provided to Parthenium seeds to study effect of environmental factors on its germination, root length and shoot length. Completely Randomized Design (CRD) was followed for the execution of the experiment. For each treatment, ten seeds of Parthenium were placed uniformly in 90 mm diameter Petri dish lined with double layered filter paper (Whatman No.1) and following studies were conducted.

2.1 Effect of Light on Germination

To evaluate the effect of light on germination, seeds were placed in Petri dish with 10 ml deionized water/Petri dish and kept under six regimes of light periods i.e. (dark), 0.5, 1, 2, 4, 8 and 16 hours. After a given light hour, the Petri dish were immediately wrapped with double layer aluminum foil in growth cabinets set at $30/20^0$C temperature to ensure no light penetration. In case of 0 h light, Petri dish was covered with aluminum foil immediately after moisture application. Wrapped Petri dishes were kept for seven days undisturbed and then were unwrapped to observe germination and then kept under natural day and light conditions. Germination was recorded 1, 2, 3 and 4 weeks after treatment (WAT).

2.2 Effect of Temperature on Germination

After adding 7 ml de-ionized water, the Petri dish were placed in growth cabinets, already set to 15/10, 20/10, 25/15, 30/20, 35/25, 40/30, and $45/35^0$C day/night temperature. Petri dishes were watered as and when required so as to keep filter paper and seed moist. Germination was recorded 1, 2, 3 and 4 weeks after treatment (WAT).

2.3 Effect of pH on Germination

The germination of seed was studied at pH 5, 7, 9 and 11 at $30/20^0$C temperature. Potassium hydroxide pellets and citric acid was used for preparing different pH solutions. Germination was recorded 1, 2, 3 and 4 weeks after treatment (WAT).

2.4 Effect of Osmotic Stress on Germination

Osmotic stress studies were conducted using -0.1, -0.2, -0.4, -0.8, -1.0 and -1.2 MPa stress at $30/20^0$C. Aqueous solution with this osmotic pressure will be made by dissolving 85.4, 127.8, 188.2, 274, 308.5, and 339.75 g of polyethylene glycol (PEG) 8000 powder in 1.0 kg distilled water [7]. Germination was recorded 1, 2, 3 and 4 weeks after treatment (WAT). Calculation of amount of PEG in g/Kg water is given below:

$$Y = -(1.18\times10^{-2})\,C-(1.18\times10^{-4})\,C^2+(2.67\times10^{-4})\,CT+(8.39\times10^{-7})\,C^2T$$

where, Y= Osmotic potential in bar, C= Concentration of PEG g/Kg H_2O, T= Temperature of water

Conversion factor: 1 atm. = 1.01251 bar, 1 bar = 1×10^5 Pa,1 bar = 0.1 MPa

2.5 Effect of Salt Stress on Germination

To study the effect of salt stress on germination, the seeds were incubated in 0 (control), 25, 50-, 75-, 100- and 125-mM sodium chloride (NaCl) solution at $30/20^0$C temperature. The solution of 125 mM concentration was prepared first as stock solution and subsequent solutions were made by dilution. 10 ml of each solution was applied in Petri dish at regular intervals to keep the seed moistened. Germination was recorded 1, 2, 3 and 4 weeks after treatment (WAT).

Formula used was 'X' mM NaCl = (Molecular wt. of NaCl × 'X' × 10^{-3})/ litre of water

Where, X =concentration of salt in mM, Molecular weight of NaCl = 58.45

2.6 Statistical Analysis and Data Transformation

All experimental data were analyzed using software S.P.S.S version 7.5. Data on the weed count and percent weed control showed high degree of variation. A linear relationship between the means and variance was observed and hence the data on weed count was subjected to angular transformation, while data on per cent control of weeds (visual) were subjected to "arcsin transformation" to make analysis of variance valid. The significance difference among treatments was tested by calculating C.D. at 5% level of significance.

3. RESULTS AND DISCUSSION

3.1 Effect of Light Periods

When the seed of Parthenium were exposed to different light periods and then kept under complete darkness for 7 days, and after that when the aluminum foil was unwrapped most of the seed were found germinated at each level of light exposure (Table 3). The seed which were not exposed to light i.e., kept in complete darkness for 1 week also germinated. Maximum germination was observed at light period of 16 h (57%) followed by 8 h (49%) and minimum at 0 h (9%) followed by 0.5 h (27%) 4 WAT. Shoot growth was comparatively more than root growth under each level of light hour treatments (Table 3). Since the initial growth of shoot occurred in dark condition when the moistened seed was wrapped with aluminum foil, therefore a shoot length of 0.91 cm was measured in Parthenium 2 WAT. Thereafter the seed was provided with normal day and light conditions and hence steady growth was attained i.e., from 0.91 to 3.15 cm 2 WAT. The maximum and minimum shoot length of Parthenium was 4.13 cm (16 h) followed by 3.01 cm (8 h) and 1.32 cm (0 h) followed by 1.41cm (0.5 h), respectively was recorded 4 WAT (Table 3). Parthenium attained maximum root length even as early as 2 weeks after sowing i.e., 2.60 cm and then steadier growth was observed with time i.e., from 2 to 4 WAT (Table 3). Maximum and minimum root length of Parthenium was 3 and 0.87 cm 4 WAT for 16 and 0 h light, respectively.

More number of seed germinated irrespective of variations in light period exposure. The average germination of Parthenium was 33.82% 4 WAT (Table 1, Fig. 1). Completely dark conditions for 1 week also resulted 8.75% germination of Parthenium 4 WAT. Results indicated that light was not a prerequisite for germination of Parthenium. Singh and Singh (2009) [8] reported that lower germination was recorded for Brazil pusley when seeds were kept in dark upto 16 h, though other seeds had no effect of light on germination. Seed of Brazil pusley placed in Light from 0 to 16 h intervals and subsequently under dark conditions, till 168 h, had only 2-10% germination compared to 59% when seeds were not subjected to dark conditions. Effect of light on germination is an indicator to confirm whether seed can germinate from deeper depths. Higher germination under both conditions i.e., light and dark shows that these weeds can germinate from deeper depths and more problematic to manage. For shoot growth, light is the prime requirement mainly for photosynthesis, even though in the beginning darkness for seven days had non-significant effect on shoot growth. It was observed that in the absence of light, achlorophyllous growth occurred during the first week. Maximum shoot length of Parthenium (4.13 cm) was recorded after 16 h of light period 4 WAS. These results are in conformity with that on *Urena lobata* which was not light dependent and emerged from depths up to 9 cm [9]. There were no significant differences in the root length when seed placed in dark or in light for initial two weeks. The average root length of Parthenium was 0.82 cm in dark and 2.79 cm in 16 h light exposure which indicates that light is required for root growth. Similar to these results it has been elucidated that the root growth was non-significant under different periods of light exposure for *Medicago denticulata, Vicia sativa, Convovulus arvensis* and *Lathyrus aphaca* [10]. There was no significant difference between maximum and minimum root length in any of the weed species under different periods of light treatments.

Table 1. Effect of light hours on germination, shoot length and root length of Parthenium

Light (h)	Germination %				Shoot length (cm)		Root length	
	1 WAT	2 WAT	3 WAT	4 WAT	2 WAT	4 WAT	2 WAT	4 WAT
0	8.75	8.75	8.75	8.75	0.91	1.32	0.76	0.87
0.5	17.50	17.50	17.50	17.50	1.08	1.41	0.88	0.97
1	26.75	26.75	26.75	26.75	1.28	1.79	0.97	1.12
2	34.25	34.25	34.25	34.25	1.51	2.06	1.33	1.50
4	44.00	44.00	44.00	44.00	1.94	2.64	1.74	1.90
8	49.00	50.00	50.00	50.00	2.19	3.01	1.91	2.16
16	56.75	57.25	57.25	57.25	3.15	4.13	2.60	3.00
SE(m)	1.45	1.45	1.45	1.45	0.10	0.14	0.13	0.14
C.D (p=0.05)	4.27	4.27	4.27	4.27	0.28	0.42	0.40	0.41

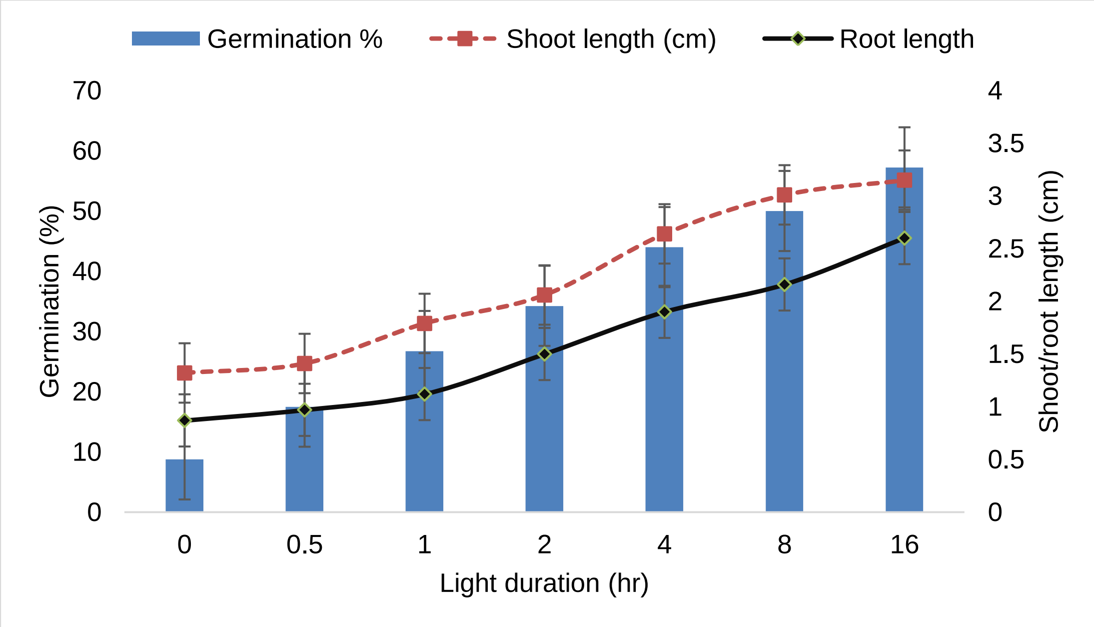

Fig. 1. Effect of light hours on germination, shoot length and root length of Parthenium after 4 weeks after treatment

3.2 Effect of Temperature

Seed germination was highest at 25/15°C when observed at different (Day/Night) temperature regimes (Table 2). Germination at 25/15°C temperature was 75, 80, 81and 81%, respectively, 1, 2, 3 and 4 weeks after treatment (WAT). The germination rate first increased from 15/10°C to 25/15°C (67-81%) and then gradually decreased with increase in temperature from 25/15°C to 40/30°C (81-2.5%). The minimum germination (2.5%) was observed at 40/30°C 4 WAT and no germination at 45/35°C. The shoot length at 25/15°C was highest; however, the shoot length at 15/10, 20/10, 25/15 and 30/20°C was statistically similar. Minimum shoot length was observed at 40/30°C i.e., 0.87 cm and 1.12 cm, 2 and 4 WAT, respectively. The shoot length gradually increased from 15/10°C to 25/15°C where the average length was highest at 25/15oC and then again decreased with further increase in temperature. The trend remained same throughout the period of 4 weeks. Remarkable root length of Parthenium was observed at all temperature regimes except 45/35°C (0 cm) and maximum being at 25/15°C (2.38 cm) followed by 20/10°C (2.24cm), 30/20°C (1.71 cm), 15/10°C (1.69 cm), 35/25°C (1.27 cm) and 40/30°C (0.41 cm) when observations were recorded 4 WAT (Table 4). The root length at 20/10°C was statistically similar to the 15/10°C at 4 WAT.

A temperature of 25°C resulted in maximum germination of 81.25 % in Parthenium 4 WAS (Table 2). Germination at 15, 20 and 30°C was also comparable to 15°C. This result clearly indicates that Parthenium can germinate well under a wide range of temperature conditions. Similar results were also reported by Singh and Singh [8] that germination of common ragweed and ivyleaf morningglory was highest at 20°C, and significantly decreased above 35 °C. Gresta et al. [11] found that *Scorpiurus subvillosus* (L.), mature scarified seeds tested at 5 to 25°C had similar germination. Many research proved that 20-30°C is suitable for seed germination of tropical plants, even 35°C is suitable for some of them [8,12]. In the present study, the shoot length of Parthenium was found maximum at 25°C. Lower temperature directed the growth of the seedlings towards optimum whereas higher temperature checked the growth of shoot. Similar findings were reported by Kumari [10] in *Medicago denticulata*, where shoot length gradually increased from 5°C to 15°C and the average length was highest at 15°C which again decreased with increase in temperature. Change in temperature may affect a number of processes during seed germination and growth including the membrane permeability, activity of membrane-bound protein and cytosol enzymes [13]. Root growth was influenced by different temperature regimes. Root length was affected significantly at

Table 2. Effect of temperature (°C) on germination (%), shoot length and root length of Parthenium

Temp (°C) Day/Night	Germination %				Shoot length (cm)		Root length (cm)	
	1 WAT	2 WAT	3 WAT	4 WAT	2 WAT	4 WAT	2 WAT	4 WAT
15/10	62.50 * (52.24)	62.50 (52.24)	67.00 (54.92)	67.00 (54.92)	1.63 (1.61)	2.92 ** (1.97)	1.04 (1.42)	1.69 (1.64)
20/10	78.25 (62.22)	79.25 (62.91)	80.50 (63.86)	80.50 (63.86)	2.25 (1.80)	3.39 (2.09)	1.45 (1.56)	2.24 (1.80)
25/15	75.00 (60.17)	80.00 (63.49)	81.25 (64.44)	81.25 (64.44)	2.27 (1.80)	3.50 (2.12)	1.65 (1.62)	2.38 (1.84)
30/20	70.00 (56.80)	72.50 (58.37)	72.50 (58.37)	72.50 (58.37)	1.92 (1.70)	3.01 (2.00)	1.16 (1.46)	1.71 (1.64)
35/25	60.00 (50.76)	61.67 (51.74)	61.67 (51.74)	61.67 (51.74)	1.27 (1.51)	2.76 (1.94)	0.90 (1.37)	1.27 (1.50)
40/30	2.50 (6.46)	2.50 (6.46)	2.50 (6.46)	2.50 (6.46)	0.87 (1.33)	1.12 (1.40)	0.31 (1.14)	0.41 (1.17)
45/35	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
SE(m)	1.94	1.77	1.79	1.79	0.09	0.10	0.05	0.05
C.D (p=0.05)	5.70	5.25	5.31	5.31	0.28	0.29	0.16	0.15

**Arc sin transformed values are in parentheses*
***Square root transformed values are in parentheses*

Table 3. Effect of pH on germination (%), shoot length and root length of Parthenium

pH	Germination %				Shoot length (cm)		Root length (cm)	
	1 WAT	2 WAT	3 WAT	4 WAT	2 WAT	4 WAT	2 WAT	4 WAT
5	62.00 * (51.97)	64.75 (53.60)	65.50 (54.06)	65.50 (54.06)	2.04 ** (1.73)	2.88 (1.97)	1.05 (1.43)	1.71 (1.64)
7	96.25 (80.61)	97.50 (83.56)	98.50 (85.07)	98.50 (85.07)	3.01 (2.00)	4.09 (2.25)	1.78 (1.66)	2.66 (1.91)
9	65.00 (53.85)	69.00 (56.35)	71.25 (57.77)	71.25 (57.77)	2.21 (1.79)	3.11 (2.03)	1.37 (1.53)	1.92 (1.70)
11	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
SE(m)	2.54	2.62	2.28	2.28	0.05	0.05	0.05	0.07
C.D (p=0.05)	7.92	8.17	7.10	7.10	0.17	0.15	0.17	0.21

**Arc sin transformed values are in parentheses*
***Square root transformed values are in parentheses*

Table 4. Effect of osmotic potential (MPa) on germination (%), shoot length and root length of Parthenium

Osmotic potential (MPa)	Germination %				Shoot length (cm)		Root length (cm)	
	1 WAT	2 WAT	3 WAT	4 WAT	2 WAT	4 WAT	2 WAT	4 WAT
0	78.00 * (62.30)	85.00 (67.53)	85.00 (67.53)	85.00 (67.53)	3.54 ** (2.13)	4.12 (2.26)	2.12 (1.76)	2.87 (1.96)
-0.1	52.50 (46.43)	55.70 (48.32)	55.70 (48.32)	55.70 (48.32)	1.93 (1.71)	2.56 (1.88)	1.24 (1.49)	1.60 (1.61)
-0.2	48.70 (44.26)	49.25 (44.55)	49.25 (44.55)	49.25 (44.55)	1.61 (1.61)	2.06 (1.75)	0.91 (1.37)	1.17 (1.47)
-0.4	30.50 (33.45)	30.50 (33.45)	30.50 (33.45)	30.50 (33.45)	1.04 (1.43)	1.33 (1.52)	0.45 (1.20)	0.58 (1.26)
-0.8	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
-1	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
-1.2	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
SE(m)	1.51	1.46	1.46	1.46	0.04	0.03	0.04	0.04
C.D (p=0.05)	4.47	4.32	4.32	4.32	0.11	0.09	0.12	0.11

**Arc sin transformed values are in parentheses*
***Square root transformed values are in parentheses*

higher temperature (0.41 cm at 40°C). Optimum root length (2.38 cm) of Parthenium was measured at 25°C. Root elongation rate reduced considerably with increase and decrease from optimum temperature. Similarly, the germination of sicklepod (*Cassia obtusifolia*) was similar between 24 to 36°C but the length of radicle and hypocotyl was more affected than germination with change in temperature (Teem et al., 1980). Some researchers have pointed out that high humidity and temperature environments may readily cause seeds to age and to lose vigour more or less [14].

3.3 Effect of pH

Seeds of Parthenium when exposed to different pH solutions, had maximum germination at 7 pH (96%) 1 WAT, whereas 65% of the seed were germinated at pH 5 (Table 3). Above pH 5 there was increase in seed germination and it was maximum at 7 pH. After that it again declined to 71% at 9 pH. There was no seed germination at 11 pH. Maximum shoot length was recorded at 7 pH i.e., 3.01 and 4.09 cm, respectively 2 and 4 WAT. Same as in seed germination, shoot length was minimum at 5 pH (2.88 cm) followed by 9 pH (3.11 cm). No shoot growth was observed at 11 pH. Maximum root length of Parthenium was recorded at distilled water i.e., 1.78 and 2.66 cm, respectively 2 and 4 WAT. No root growth was observed at 11 pH even 4 WAT. There was decrease in root length with increase or decrease in pH level from optimum pH i.e., 7.

Seeds of Parthenium germinated in both acidic and alkaline conditions (5 and 9 pH). The maximum germination of Parthenium was observed at 7 pH and no germination at 11 pH (Table 3). The results indicate that parthenium seeds have a good capacity to germinate under wide ranges of pH. Singh and Singh [8] reported that pH range of 5 to 11 had no adverse effect on germination of twelve weed species, while germination of prickly sida was highest at pH 9 and any increase or decrease in pH resulted in reduced germination. Ahlawat et al. [15] also observed same type of response and concluded that alkalinity and acidity of a wide range do not seem to pose any problem in parthenium, which is highly adapted to varied ecological habitats. Maximum shoot length of Parthenium was observed in distilled water (4.09 cm) 4 WAT. Growth of shoot was restricted at 11 pH while it showed normal growth at 5 and 9 pH, which indicates that it grows well in acidic and alkaline conditions both. Dekker et al. [16] reported that there was decrease in shoot height by number of leaves and main axis shoots, as well as by shoot height of quack grass with decrease in pH levels. Root length follow the same trend that of shoot length i.e., maximum (2.66 cm) with distilled water, 4 WAT. This demonstrates genetic variability of Parthenium to different pH conditions. With decrease in soil pH from 6.2 to 3.7, quack grass plant accumulated less rhizome and root biomass [16].

3.4 Effect of Osmotic Potential

As osmotic potential was decreased from 0 to -0.8 MPa, seed germination decreased substantially (Table 4). No germination occurred at osmotic potential of -0.8 to -1.2 MPa. When water potential was 0 MPa, germination was maximum i.e., 85% at 2 WAT and no increase at 3 and 4 WAT. Germination of Parthenium at -0.1 and -0.2 MPa did not differ significantly. Significantly lower germination was recorded at -0.4 compared to 0, -0.1 and -0.2 MPa and no germination observed from -0.8 to -1.2 MPa even after 4 WAT. As osmotic stress was increased, shoot length in Parthenium decreased from 3.54 to 1.04 cm 2 WAT. Shoot length of Parthenium was 4.12, 2.56, 2.05 and 1.32 cm at 4 WAT at osmotic potential of 0, -0.1, -0.2 and -0.4 MPa, respectively. No shoot growth was observed beyond -0.4 MPa. Root length was measured significantly more at 0 MPa and beyond that significant decline in shoot length was recorded 4 WAT. Maximum root length of Parthenium was recorded only in deionized water and decreased significantly as the osmotic potential lowered from 0 to -0.8 MPa. Maximum root length of 2.87 cm in deionized water followed by 1.60 cm in -0.1 MPa and minimum root length of 0.58 cm in -0.4 MPa followed by 1.17 cm in -0.2 MPa was recorded 4 WAT. There was no radical emergence beyond -0.4 MPa.

Substantial decrease in germination occurred when water potential decreased from 0 to -0.8 MPa. Germination of Parthenium seeds was inhibited at lower level of osmotic stress (Table 4); no germination was recorded with further lowering the osmotic potential. According to Bradford [17] seed germination is a process of growth of a previously quiescent or dormant seed starting with the imbibition of water. Seed imbibition rate and germination level normally decreases as the surrounding water potential decreases, the critical hydration level for seed germination is species-specific [18]. Shoot length of Parthenium decreased with increase in osmotic potential from 0 to -0.8 MPa. In spite of the significant reduction in shoot length at each level, a remarkable length of 2.05 cm was measured for Parthenium shoots, 4 WAT at -0.2 MPa osmotic potential. In contrast to this osmotic potential of -0.3 MPa did not affect the growth of spider plant (*Cleome gynandra* L.) and this species could survive, grow and reproduce when exposed to an osmotic potential up to -0.9 MPa; due to the remarkable capacity of this species for osmotic adjustment [19]. Growth of root was restricted markedly with lowering the osmotic potential from 0 to -1.2 MPa. Normal root growth was recorded at non-stressed osmotic potential i.e., 0 (control). Root length was more at 0 MPa and least at -0.4 MPa osmotic potential, whereas no radicle was observed at -0.8 MPa, 4 WAT. Slow root elongation is attributed to the lower osmotic potential, which restricts the movement of water to roots. Results are in line with Norsworthy and Oliveira [20] where radicle and hypocotyl length of *Senna obtusifolia* decreased with decreasing solution osmotic potential and no germination occurred at a solution osmotic potential of – 0.75 MPa.

3.5 Effect of Salt Stress

Seed germination was significantly affected by salinity levels in Parthenium. Maximum germination was recorded in distilled water (Table 5). Seed germination was significantly reduced with all concentrations of NaCl (salinity) level of above 25 mM. Germination was >50 % up to 75 mM NaCl and then decreased to 47 and 43 % at 100 and 125 mM, respectively. Shoot length decreased similar to germination with increase in NaCl concentration in the solution. Maximum shoot length of 3.8 cm was reported in distilled water 4 WAT. Shoot growth of Parthenium was at par from 25 to 50 mM and 75 to 125 mM concentration i.e., 2.34 to 2.18 cm and 1.67 to 1.27 cm, respectively 2 WAT. A root length of 2.46 cm (4 WAT) was observed in distilled water which was significantly higher than all the levels of NaCl. Radicle of Parthenium was discernible even at higher salt concentration of 125 mM. Higher concentration of NaCl (125 mM) recorded maximum reduction in root length of Parthenium.

The ability of Parthenium seeds to tolerate salinity (43-85%) at the time of germination varied significantly from distilled water to 125 mM NaCl concentration (Table 5). Germination of Parthenium was inversely related to NaCl concentrations, where maximum germination occurred (84.5%) in distilled water and minimum germination (42.75%) with 125 mM salt concentration. The effect of salinity on germination is usually attributed to either osmotic effects due to declining solute potential or to toxicity effect due to uptake and/or accumulation of some ions in seed as sodium and chloride [21,22]. In addition, toxicity of NaCl during seed germination is usually associated with a significant decrease in the seed K+ content, which could reduce metabolic functions and ultimately reduce germination and seedling growth [23]. NaCl concentration had adverse effects on the shoot growth i.e., with increase in salt concentration, there was decrease in shoot length. Parthenium was able to grow after one week even at 125 mM NaCl. Similar results were reported by Srivastava [24] that in saline medium, excessive amounts of metabolic energy are wasted for the uptake of ions that results in decreased availability of energy for other growth and developmental processes in salt stressed plants.

Table 5. Effect salt stress (mM) on germination (%), shoot length and root length of Parthenium

NaCl conc. (mM)	Germination %				Shoot length (cm)		Root length (cm)	
	1 WAT	2 WAT	3 WAT	4 WAT	2 WAT	4 WAT	2 WAT	4 WAT
0	84.00	84.50	84.50	84.50	3.14	3.80	2.21	2.46
25	59.75	61.50	61.50	61.50	2.34	2.62	1.91	2.08
50	53.50	55.75	55.75	55.75	2.18	2.56	1.61	1.69
75	52.00	52.50	52.50	52.50	1.67	1.97	1.56	1.65
100	46.75	47.50	47.50	47.50	1.32	1.53	1.31	1.40
125	42.75	42.75	42.75	42.75	1.27	1.39	0.87	0.92
SE(m)	1.90	1.88	1.88	1.88	0.20	0.19	0.17	0.17
C.D (p=0.05)	5.68	5.64	5.64	5.64	0.62	0.57	0.50	0.50

3.6 Summary

The different periods of light exposure and total darkness had stimulatory effect on germination, root and shoot growth indicating that light was a prerequisite for the germination of Parthenium. It was found to germinate over a wide range of temperature (15-35°C) with maximum germination at 20°C whereas, root and shoot growth was maximum at 25°C. Maximum germination, root and shoot growth recorded in distilled water and no germination at 11 pH. Decrease in osmotic potential from 0 to -0.8 MPa accompanied by decrease in germination and growth of P. hysterophorus with maximum being at 0 MPa and no germination at -0.8 MPa. Maximum germination was recorded at 0 mM NaCl concentrations whereas, minimum germination was (42.75%) at 125 mM. Hence, appropriate study of the effect of environmental factors on parthenium will certainly leads to formulation of better weed management practices for the noxious weed.

4. CONCLUSION

From the current study it has been concluded that the current research paper explored the growth behavior of *Parthenium hysterophorus* and its response to various environmental factors. Through a comprehensive analysis of available literature and experimental data, it is evident that the environmental factors such as light periods, temperature, pH, osmotic potential and salt stress significantly influence the growth behaviour viz., germination, shoot and root length of this invasive weed. The findings highlight the importance of understanding the ecological requirements and adaptive strategies of *Parthenium hysterophorus* in order to effectively manage its spread and mitigate its negative impacts on ecosystems and human health. Further research is warranted to investigate additional factors that may influence the growth behavior of *Parthenium hysterophorus* and develop sustainable management strategies. Overall, this study contributes to our understanding of the ecological dynamics of *Parthenium* and provides valuable insights for future research and weed management efforts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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