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Effect of UV-C irradiation on seed germination, growth, vigor index and viability of different varieties of Gujarat Amaranthus

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Abstract
This study investigated the effects of ultraviolet-C irradiation on seed germination, seedling growth, vigor index, and viability of different *Amaranthus hypochondriacus L.* varieties. Seeds were exposed to UV-C light for varying durations and then germinated under laboratory conditions. The results showed that UV-C exposure had both stimulatory and inhibitory effects, depending on the exposure duration and seed variety. The highest germination rate was observed in GA6 seeds after 30 minutes of UV-C exposure, while the lowest germination rate occurred in GA6 seeds after 10 minutes. Seedling growth analysis revealed that GA6 exhibited significantly longer radicle and plumule lengths after 30 minutes of UV-C exposure. Seed vigor was highest in GA6 at 30 minutes of exposure, and viability tests showed that seeds from GA5 and GA6 retained higher viability at longer UV-C exposure durations. The study concluded that UV-C irradiation can positively influence seed performance in *Amaranthus hypochondriacus L.*, but its effectiveness depends on both exposure duration and seed variety.

Keywords: *Amaranthus hypochondriacus L.*, ultraviolet, irradiation, seed vigor index, viability

Introduction

Physical treatment methods are regarded as one of the safest approaches to enhance seed germination and promote plant growth, primarily due to their minimal adverse effects on the environment. Physical factors have been utilized to elicit beneficial biological changes in plants without compromising their ecological balance (Govindaraj *et al.*, 2017) [14]. The prevailing views on the physical factors currently employed for seed treatments predominantly involve electromagnetic waves, including ultraviolet and microwave radiation, ultrasound, lasers, and ionizing radiation. Among these physical treatments, microwave and UV radiation are deemed the most significant pre-sowing seed treatments (Araujo *et al.*, 2016) [1].

Ultraviolet (UV) radiation is classified as electromagnetic radiation, which has historically been categorized into three wavelength ranges: UV-A (320-390 nm), UV-B (280-320 nm), and UV-C (100-280 nm). Within these ranges, UV-C radiation is highly photochemically active and biologically lethal, and it has been utilized by various researchers to promote the germination of maize and sugar beet seeds. Furthermore, UV-C irradiation has been applied to enhance seed germination and growth parameters in wheat (Nasur & Lazim, 2001; Rupiasih & Vidyasagar, 2016) [23, 27] and groundnut (Neelamegam & Sutha, 2015) [24].

Irradiation refers to a technique that applies radiation to substances or plant materials. During the irradiation process, high-energy radiation penetrates matter, inducing ionizing, electric, or magnetic disturbances that influence the internal structure or composition of plants. Over the past few decades, the issue of ozone depletion has prompted extensive research into the responses of higher plants to UV radiation (Caldwell and Flint, 1994). When subjected to increased UV radiation, higher plants display a range of physiological and morphological alterations (Bjorn, 1996; Greenberg *et al.*, 1997; Rozema *et al.*, 1997; Caldwell *et al.*, 1998) [6, 15, 29, 10], with significant variations observed among species (Barnes *et al.*, 1990; Day, 1993; Mc Leod and Newsham, 1997) [7, 11, 22] and among varieties.

Seed germination and vigor are crucial factors in seed technology, with researchers and farmers consistently striving to implement effective seed treatment and enhancement both prior to and following sowing.

Nevertheless, the negative impacts of seed treatment have yet to be assessed during periods of high production and productivity. Achieving sustainability in agriculture represents one of the significant challenges humanity faces in preserving ecology and maintaining resources for future generations (Edmondson *et al*., 2014) [12]. The primary objective for every nation is to utilize technology and innovative methods to minimize chemical usage and ensure environmental safety for sustainable agriculture (Pretty *et al*., 2006) [25]. Neelamegam and Sutha (2015) [24] found that groundnut plants exhibited enhanced germination and seedling vigor following 60 minutes of UV-C irradiation treatment. Conversely, some researchers have noted adverse effects of UV radiation on seed treatment. Wang *et al*. (2018) [39] reported that UV light seed treatment negatively impacts nutrient metabolism and seed germinability post-treatment. Additionally, Lizana *et al*. (2009) [19] indicated that the application of short wavelength UV-B radiation inhibits hypocotyl growth and reduces elongation in cucumber seeds.

In today's agricultural landscape, there is a prevalent reliance on substantial quantities of chemicals and toxic substances to achieve greater yields, often without regard for ecological balance and sustainability. Employing cultural and physical techniques may yield more favorable outcomes for improved agricultural results (Aladjadjiyan, 2012) [2].

Materials and Methods

Preparation of experimental setup

The current experiments were conducted at Pramukh Swami Science and H.D. Patel Arts College, Kadi, India, to assess the effects of ultraviolet (UV)-C irradiation on the seed germination parameters of *Amaranthus hypochondriacus* L. (varieties GA1, GA3, GA5, and GA6) *in vitro*. Seeds were sourced from Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar-385506, Banaskantha and Gujarat, India. The seeds were subsequently placed into plastic bags, and all experiments were performed in triplicate, with mean values utilized for the analysis of results.

Seed Selection & UV-C treatment of seeds

Seeds of *Amaranthus hypochondriacus L*. were chosen based on their uniform size and shape. Initial experiments were carried out to identify the suitable doses at the correct timing, exposing seeds from each variety of *Amaranthus hypochondriacus L*. to UV-C irradiation in a UV-C Chamber (Livpure Pvt. Ltd., Gurugram-122016 and Haryana, India) for varying exposure times of UV-C irradiance (Figure 1).

Fig 1: UV-C treatment of amaranthus seeds

The UV-C radiation was provided by two tubular lamps (Philips, TUV 8 W G8 T5) that emitted UV-C light at a wavelength of 254 nm. The distance from the seeds to the UV-C radiation lamps was roughly 15 cm. UV-C radiation was applied individually to the seeds of *Amaranthus hypochondriacus* L. (GA1, GA3, GA5, GA6) for durations of 5, 10, 15, 20, 25, and 30 minutes, with non-irradiated seeds serving as controls. Following the UV-C irradiation treatments, the seeds were planted under laboratory conditions in petri dishes containing moist filter paper and half-strength MS media, and were incubated in a BOD incubator at 25ºC in the dark. After two days, cumulative seed germination was monitored daily at 24-hour intervals, and the percentage of germinated seeds was recorded until the seventh day, at which point no additional seeds germinated. To assess the impact of UV-C treatment on Amaranthus seeds, several germination parameters were calculated as follows.

Seed germination percentage (%)

Subsequently, the number of seeds that germinated in each petri dish was recorded and monitored daily to track the onset and development of germination until no further germination was observed for over a week. Seeds were deemed germinated when the radical reached a length of approximately 2 mm or more. The final germination percentage reflects the total number of seedlings counted at the conclusion of the test after seven days, calculated as follows.

Formula

The germination percentage is determined using the following formula (Iqbal MZ *et al*., 1992) [18]. After a week of incubation, the percentage of germination was computed. The experiment was conducted three times, with four replicates for each variety.

$$\text{Percentage of Germination} = \frac{\text{No of seed germinated}}{\text{Total No of seeds planted}} \times 100$$

Seedling length (cm)

At the conclusion of the germination period, we assessed the shoot (plumule) and the primary root (radicle) of the normal seedlings from each treatment in every replication after one week, calculating the average length of each component. The results for the number of normal seedlings were recorded in cm, consistent with the methodology outlined by Vieira and Carvalho in 1994 [38].

Seedling vigor index (S.V.I.)

The seed vigor index encompasses the characteristics of the seed that influence its activity level and performance during germination and seedling emergence (Lu, X. *et al*., 2007; Huang M, *et al*., 2017) [20, 17]. The seedling vigor index is computed using the following formula (Abul Baki *et al*., 1973; Bewly JD *et al*., 1982; Suthar *et al*., 2014) [4, 8, 35]. The seedling vigor index was determined by multiplying the germination percentage (%) by the total seedling length (cm) of the same seed lot on the seventh day, as per Muthusamy *et al*., 2012 [5].

Seed Vigor index (SVI) = Germination percentage × Seedling length (cm)

Viability

The viability of seeds or plants refers to the proportion of seeds or plant material in a batch that are alive and capable of developing into plants that can reproduce under suitable field conditions.

$$\text{Percentage of Viability} = \frac{\text{Total no. of Viable seeds} \times 100}{\text{Total No of seeds planted}}$$

Experimental Design and Statistical Data Analysis

The experimental designs were conducted three times utilizing a completely randomized block design. All data were statistically analyzed using one-way ANOVA with the Web Agri Stat Package 2.0 software. The results are shown as means ± S.D. (Standard Deviation). Data from the control group and various treatments were evaluated using Duncan's multiple range test at $p<0.05$.

Results and Discussion

The findings from the experiments regarding the impact of UV-C irradiation on *Amaranthus hypochondriacus L.* seeds are presented in (Table-1). The results indicate that the majority of UV-C irradiation treatments across all exposure times significantly influenced all germination parameters studied, with the exception of the mean germination time. This study aimed to explore the effects of UV-C irradiation on seed germination, seedling growth, vigor index, and viability of *Amaranthus hypochondriacus L.* (GA1, GA3, GA5, and GA6). The experimental treatments consisted of UV-C exposure durations of 0 minutes (Control), 5, 10, 15, 20, 25, and 30 minutes for the seeds of *Amaranthus hypochondriacus L.* Following irradiation, the seeds were germinated on both moist filter paper and half-strength MS Media. After a one-week incubation period, the plates were examined, and measurements were taken for seed germination percentage (%), seedling length (cm), vigor index, and viability.

Table 1: Effect of UV-C irradiation of *Amaranthus hypochondriacus L.* varieties on seed germination, growth, vigor index and viability

Growth Parameters	Amaranthus varieties		UV-C exposure duration						
			Control	5 min.	10 min.	15 min.	20 min.	25 min.	30 min.
Seed germination%	GA1		70	40	40	80	40	40	30
	GA3		20	30	40	40	10	40	10
	GA5		70	70	80	70	70	80	70
	GA6		70	100	60	80	100	80	100
Seedling length (cm)	GA1	Radicle	3.4	4.2	5.8	3.5	3.3	6.1	2.8
		Plumule	5.5	5.1	7.7	4.5	5.8	8.3	5.9
	GA3	Radicle	1	0.9	0.3	2.3	4	2.4	3.8
		Plumule	0	1.2	1.7	6.1	6.5	7.1	7
	GA5	Radicle	3.2	3.8	4.1	5.5	2.3	3.2	5.2
		Plumule	6.2	5.9	7.2	7	4.1	6.1	7.3
	GA6	Radicle	5.2	5	4.2	4.1	4.3	4.2	5.6
		Plumule	6.3	5.9	5.4	5.4	7.6	6.4	9.3
Vigor index	GA1		623	372	540	640	352	576	261
	GA3		20	63	80	336	105	380	108
	GA5		658	679	791	875	448	744	875
	GA6		805	1090	960	760	1190	848	1490
Viability	GA1		70	40	50	80	60	50	30
	GA3		20	30	50	40	40	40	20
	GA5		70	70	80	70	80	90	90
	GA6		70	100	70	80	100	100	100

Amaranthus hypochondriacus L. varieties (GA1, GA3, GA5, GA6)

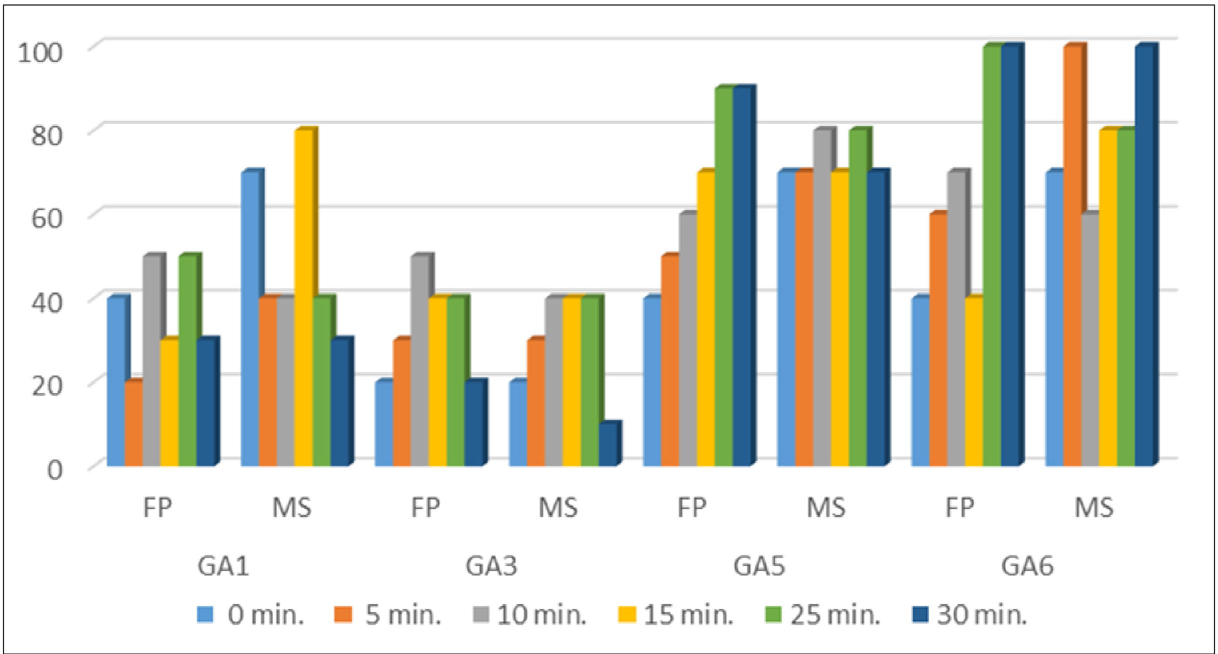


Fig 2: Seed germination of *Amaranthus hypochondriacus* L. varieties on moist filter paper and half strength MS media

The results demonstrated that increasing the duration of UV-C irradiation enhanced the promotive effect on the seed germination of *Amaranthus hypochondriacus L.* when compared to the control and shorter UV-C exposure durations. The highest seed germination percentage (100%) was observed with a 30-minute UV-C exposure duration for Amaranthus seeds (GA6). Conversely, the lowest seed germination percentage (60%) was recorded at 10-min UV-C exposure duration. Additionally, contradictory results indicated that a 30-minute UV-C exposure duration resulted in a 70% seed germination rate, while an 80% germination rate was noted at a 25 min UV-C exposure time for Amaranthus seeds of GA5 (Table-1 & Figure 2). The seed germination percentage was 40% at 10, 15, and 25 minutes of UV-C exposure for Amaranthus seeds of GA3.

Furthermore, the effects of UV irradiation, both positive and negative, during a single treatment have been extensively researched by numerous scientists. Rupiasih and Vidyasagar demonstrated that wheat seeds exposed to UV-C radiation experienced a stimulation in seed germination. Numerous reports indicate that UV rays can cause damage to plants, leading to changes in growth, development, and morphology. Conversely, Ambaru *et al*. reported an enhancement in seed germination for UV-A irradiated Capsicum annum. The germination percentage was observed to gradually decline with an increase in UV-C exposure time, with Amaranthus (GA1) seeds showing a 70% germination rate under control conditions (no UV-C exposure) compared to other durations of UV-C exposure (Figure 2). Moreover, although there was no significant effect on the mean germination time, the most substantial reductions of 30% and 10% in seed germination rates were noted at 30 minutes of UV-C exposure for GA3 and GA1, respectively (Table-1 & Figure 2). Peykarestan and Seify found that the percentage of germination and the growth rates of red bean sprouts were inversely related to the doses of UV irradiation. From these findings, it was noted that low UV-C exposure times stimulated seed germination, while longer exposure times of 30 minutes inhibited it. This indicates that the impact of UV-C irradiation on seeds can yield both positive and negative outcomes for seed germination, depending on the duration of UV-C exposure and the varieties of *Amaranthus hypochondriacus L.* seeds.

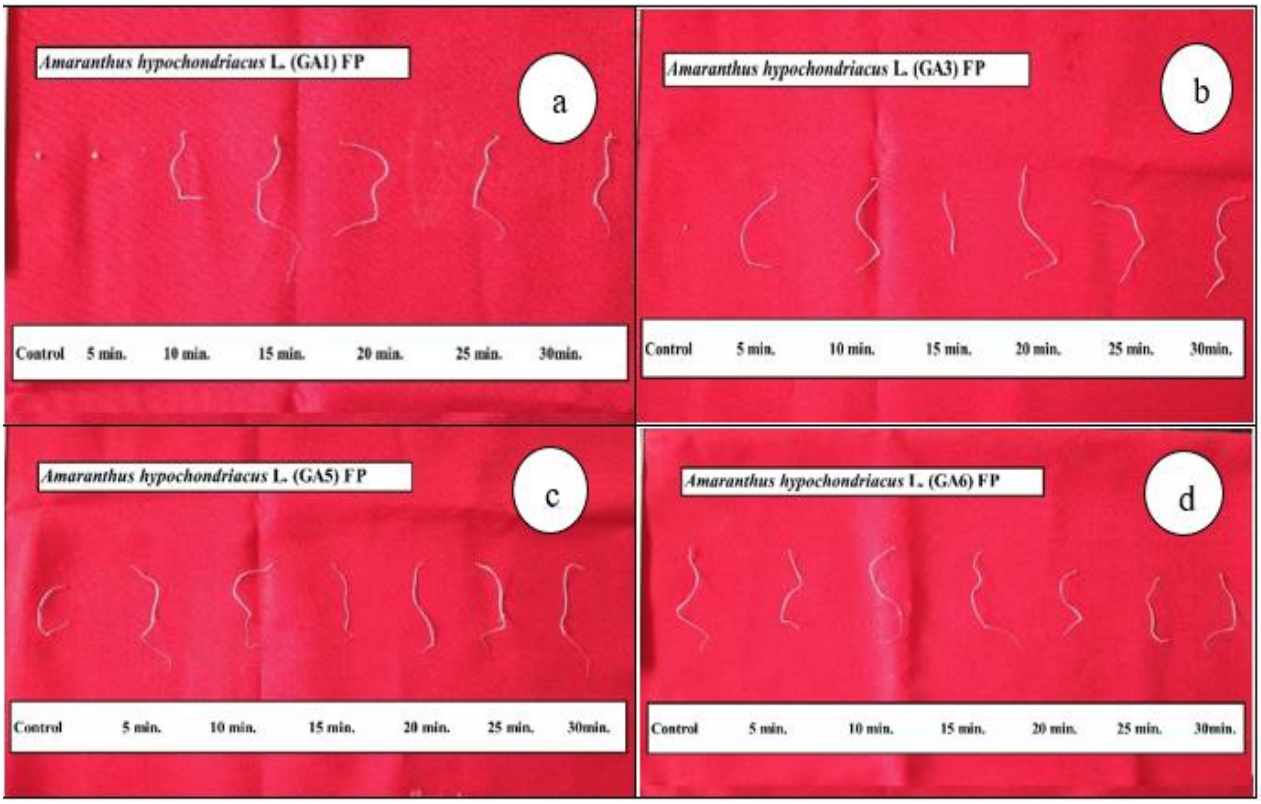
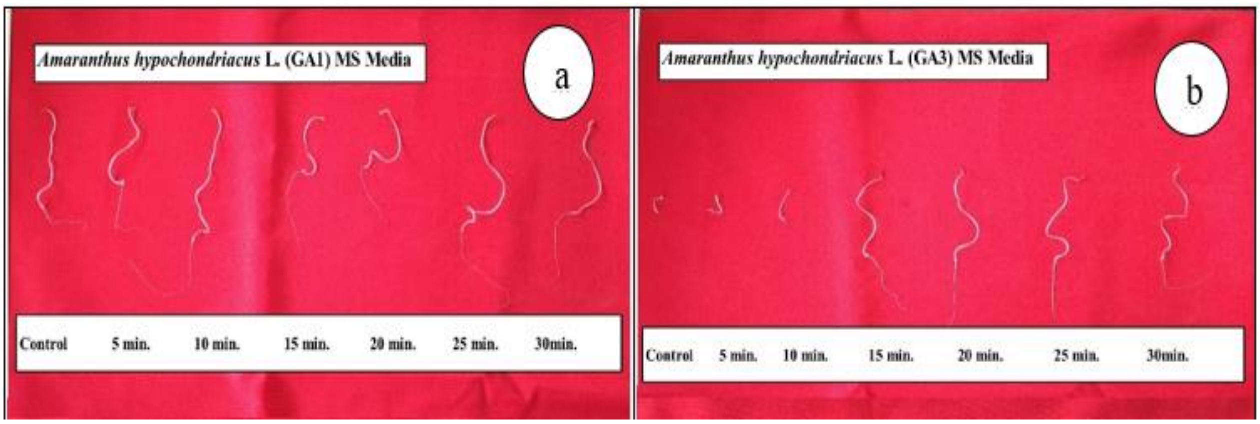


Fig 3: Seedling length of *Amaranthus hypochondriacus L.* varierties on moist filter paper of Control (UV-C Treatment –o min.) and UV-C treated seeds (a) GA1, (b) GA3, (c) GA5, (d) GA6



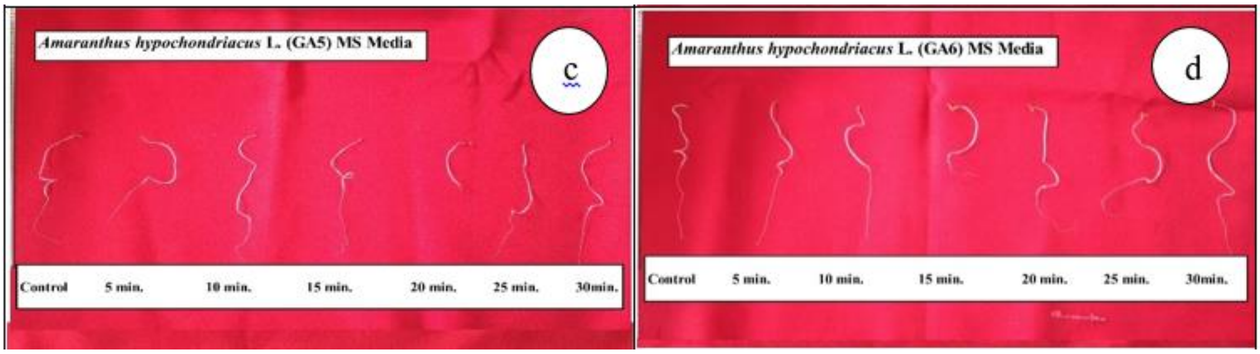


Fig 4: Seedling length of *Amaranthus hypochondriacus L.* varierties on half strength MS media of Control (UV-C Treatment-o min.) and UV-C treated seeds (a) GA1, (b) GA3, (c) GA5, (d) GA6

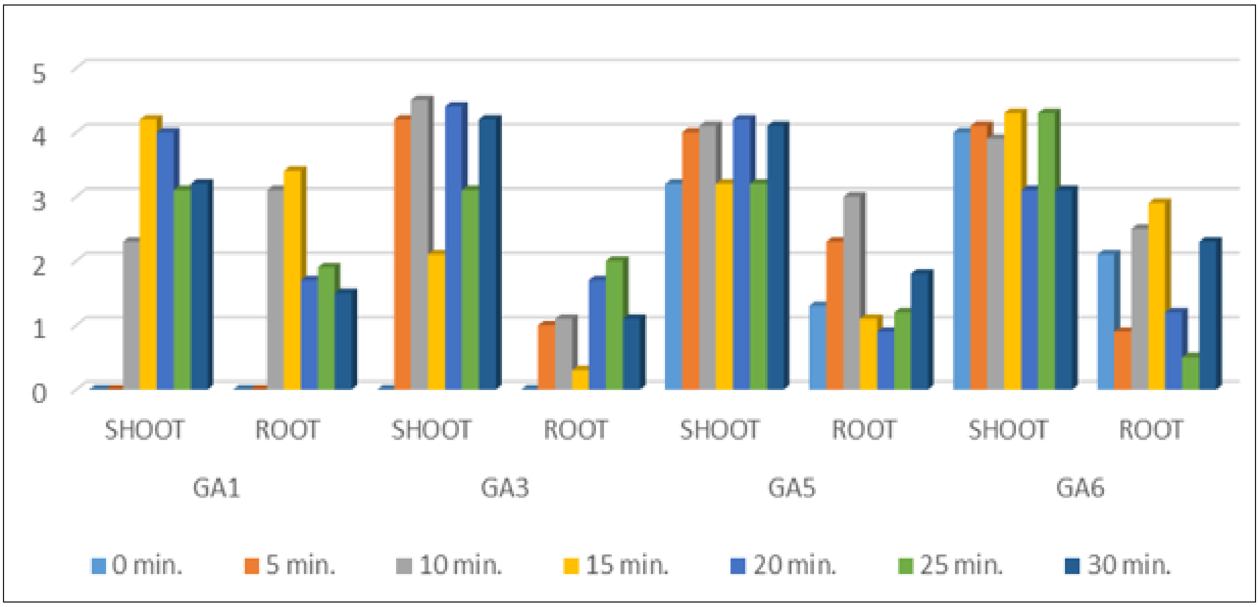


Fig 5: Seedling length of *Amaranthus hypochondriacus* L. varieties on moist filter paper

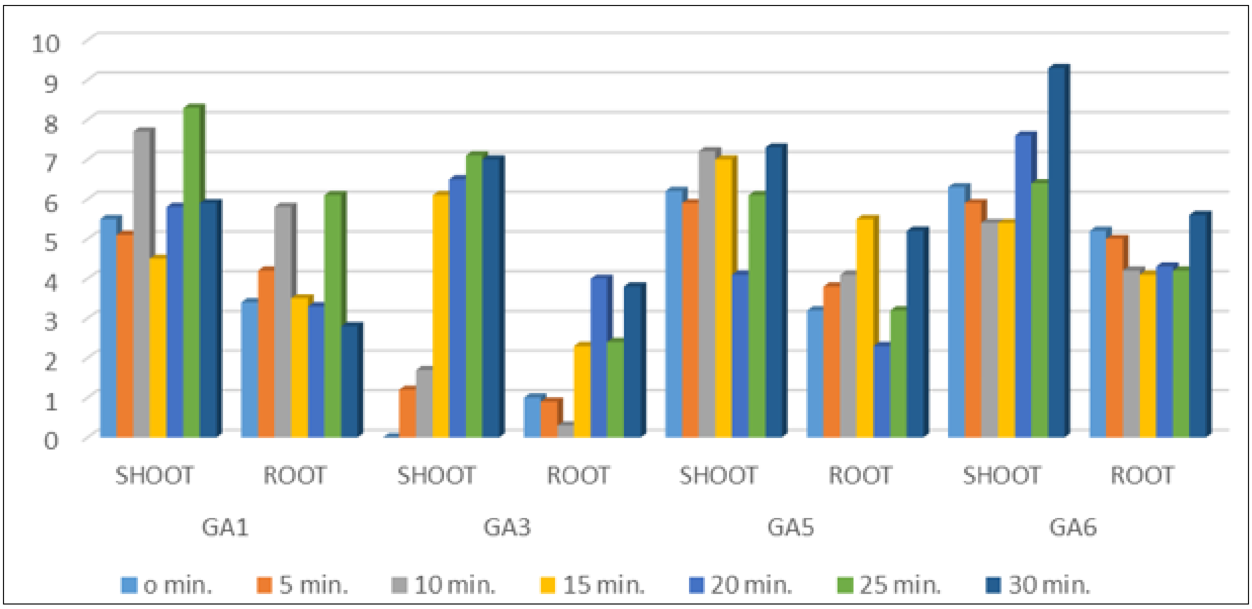


Fig 6: Seedling length of *Amaranthus hypochondriacus L.* varieties on half strength MS Media

The UV-C exposure significantly differed from the control (no UV-C exposure) regarding seedling growth. The GA6 seeds exhibited nearly identical radical lengths at 10, 20, and 25 minutes of UV-C exposure, but were significantly greater at 30 minutes (Table-1 & Figure 6). The experiment also indicated that UV-C exposure promoted the growth of the radical and plumule significantly more than the control treatment of GA5. Increased UV-C exposure resulted in reduced seedling growth in GA1 (Table-1 & Figure 4.a). The development of shoots in GA3 exhibited positive growth, with shoot growth increasing alongside UV-C exposure when compared to the control. This finding clearly indicates that GA6 seeds demonstrated longer radical and plumule growth than GA1, GA3 and GA5 as UV-C exposure increased (Table

1 & Figure 6).

Torres *et al*. discovered that the percentage of normal sunflower seedlings decreased when seeds were exposed to UV-C radiation for durations ranging from 5 to 60 minutes. Siddiqui *et al*. noted an increase in shoot weight, shoot length, root length, root weight, and leaf area in groundnut and mung bean when seeds were subjected to UV-C radiation for periods of 10, 15, 30, and 60 minutes. This aligns with the current study, which shows an enhancement in seed germination, seedling growth, and both shoot and root elongation of Bengal gram (*Cicer arietinum* L.) with increasing exposure times of up to 17 minutes of UV-C irradiation compared to the control and horse gram (*Macrotyloma uniflorum* L.) seeds.

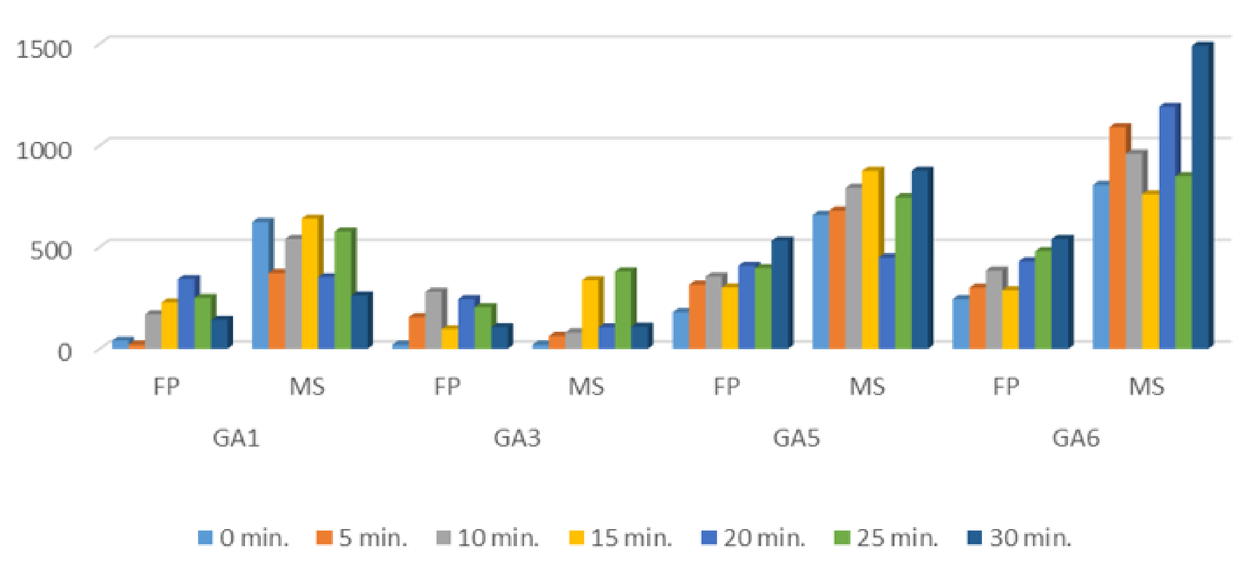


Fig 7: Vigor index of *Amaranthus hypochondriacus L*. varieties on moist filter paper and half strength MS Media

Seed vigor plays a crucial role in determining the potential for quick and uniform plant emergence across various field conditions. (Rajjou L, *et al*., 2012; Finch-Savage *et al*., 2010) [30, 13]. The concept of seedling vigor primarily reflects the weight or height of seedlings, often overlooking the speed of germination (Lu X, *et al*., 2007; Lowe LB, *et al*., 1972) [20, 21]. Factors such as seed weight and nutrient content significantly influence plant growth during the seedling stage (*Vandamme* E, *et al*., 2016; Ries SK, *et al*., 1973) [37, 31]. A high level of seed vigor is linked to enhanced growth and productivity in agricultural settings (Han Z, *et al*., 2014) [16]. Notably, a high seed vigor value was recorded after 30 minutes of UV-C exposure, while a reduction was observed at 15 minutes in GA6 UV-C exposure (Table-1 & Figure 7). In a similar vein, GA5 exhibited the highest vigor index value after 30 minutes of UV-C exposure when compared to GA1 and GA3. In the case of GA1, the control treatment (no exposure) showed a significant difference from the other exposure durations.

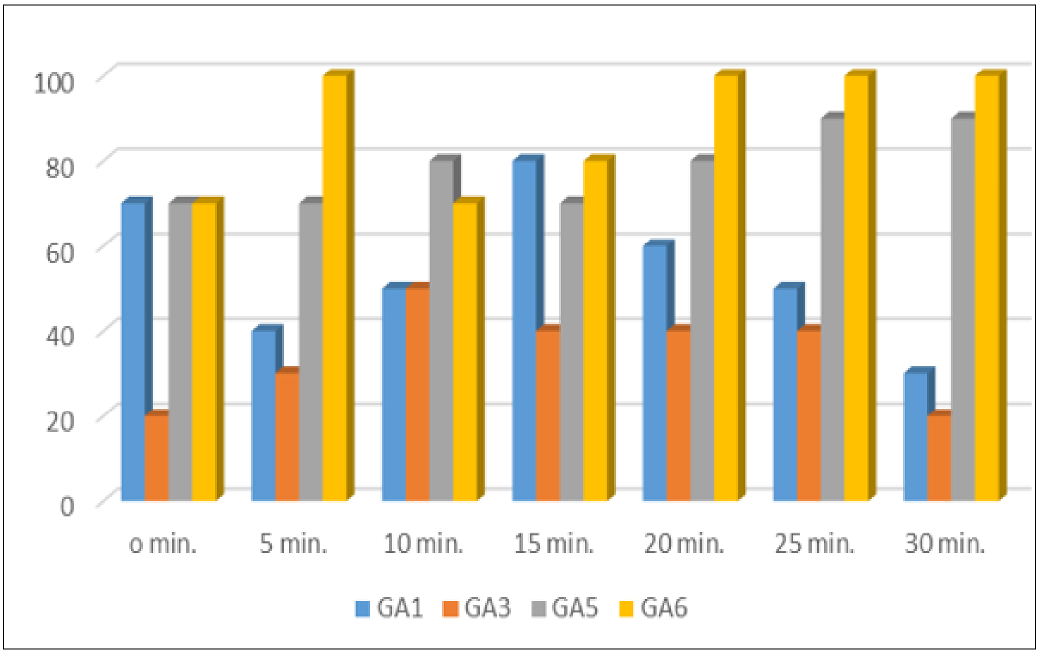


Fig 8: Viability of *Amaranthus hypochondriacus* L. varieties

Table1 & Figure 8 illustrates that the seeds of Amaranthus GA5 and GA6 remain more viable when subjected to UV-C irradiation for 20, 25, and 30 minutes compared to GA1 and GA3. Conversely, the 25 and 30 minutes of UV-C exposure diminished the seed viability of GA1 and GA3 relative to other exposure times.

Conclusions

In conclusion, we determined that UV-C irradiation has both positive and negative effects on seed germination, growth, vigor index, and viability, which are influenced by the duration of UV-C exposure and the various varieties of *Amaranthus hypochondriacus* L. seeds. The GA5 and GA6 varieties exhibited greater tolerance to prolonged UV-C exposure, while GA1 and GA3 were found to be the most sensitive to it.

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