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Effect of thermophysical methods like hot water, hot air and microwave seed treatment on seed quality parameters, seedling growth parameters and diseases incidence in bell pepper (*Capsicum annuum*)

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ABSTRACT

The study was conducted to standardise effect of temperature and duration of thermophysical seed treatment on seed quality and plant growth parameters in bell pepper. In vitro screening of thermophysical methods viz hot water treatment at four different temperature-duration combinations of 49, 50, 51 and 52°C for 30, 45 and 60 min; hot air treatment at four different temperature-duration combinations of 70, 72, 74 and 76°C for 24, 36, 48 and 60 min and microwave seed treatment for 5, 10, 15, 20 and 30 sec along with control was done. The three best treatments among each category viz hot water, hot air and microwave seed treatment were used for further evaluation under nursery condition. In hot water, seed treatment at 50°C for 60 min resulted in highest seed germination (89.50%). In hot air, seed treatment at 72°C for 24 h resulted in highest seedling length (10.43 cm) at par with control (10.48 cm) and SVI-I (length) (769.25) and SVI-II (mass) (159.46), though lower than control. In microwave seed treatment, highest germination (91.25 and 90.00%), SVI-I (length) (1,092.83 and 1,057.73) and SVI-II (mass) (218.33 and 214.20) were recorded in 5 and 10 sec exposure, respectively. In the nursery, seed treatment in hot water at 50°C for 60 min and in microwave for 5 sec resulted in highest total seedling emergence (85.16 and 84.00% respectively) and height at 42 days after sowing (11.20 and 11.40 cm respectively); in hot water at 50°C for 60 min and microwave for 5 sec to minimum ungerminated seeds (14.84 and 16.00% respectively); in hot water at 50°C for 60 min in lowest damping-off incidence (6.94%) and in hot air at 74°C for 48 h (4.44%) and in hot water at 50°C for 60 min (5.00%) in minimum virus infection.

Keywords: Bell pepper; seed treatment; hot water treatment; hot air treatment; microwave treatment

INTRODUCTION

Bell pepper (*Capsicum annuum* L), that belongs to Solanaceae family, is also called as Shimla Mirch, sweet pepper and capsicum and has an immense nutritive value, flavour, aroma and colour. In Himachal Pradesh, bell pepper is cultivated as summer and rainy season crop and, because of high humidity and soil moisture coupled with moderate temperature, the incidence and severity of diseases is high. Most of the diseases are seed borne in nature and are carried through infected seeds viz anthracnose (*Colletotrichum capsici*), cercospora leaf spot (*Cercospora capsici*), bacterial spot (*Xanthomonas campestris* pv *vesicatoria*), phytophthora rot (*Phytophthora capsici*) and viral diseases. Under use of thermophysical methods for disease management and plant growth are getting more popular due to their least deleterious effects on environment and human health as compared to chemicals. The temperature-time combinations, pathogen is killed in or on the seeds without affecting the seed germination and viability.

Hot water treatment has been successfully applied to manage seed borne diseases in vegetable crops. Hot air treatment is another thermophysical method used for the treatment of various types of seeds and also considered as useful and effective disinfection method of seeds for controlling seed borne diseases in vegetables although the treatment needs to be carefully performed to maintain the germination of seeds. Microwave radiation treatment is a new thermophysical method used for the control of seed borne pathogens and, thereby, increase the plant health and growth. Hence, keeping in view all above mentioned facts, the present investigations were carried out to determine the effect of hot water, hot air and microwave seed treatment on plant growth and disease incidence in bell pepper.

MATERIAL and METHODS

The experiment was conducted on bell pepper cv Solan Bharpur in the laboratory and experimental farm of Department of Seed Science and Technology, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh during 2019 and 2020.

The seeds of bell pepper were procured from the Department of Seed science and Technology, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh which were 6 months old and the standard germination percentage of seeds was 85 per cent.

Hot water bath works thermostatically controlling temperature with time. The seeds were pre-soaked in sterilized distilled water for 15 min wrapped in muslin cloth in glass jar. Water bath was filled with 3 litres of water and device was connected with electricity. Temperature was set through digital PID (proportional integral derivative) controller. The device took around 10 minutes to reach the desired temperature. Once the desired temperature was acquired, the pre-soaked seeds in muslin cloth were dipped in hot water for a fixed period of time as per the treatment details (49°C/30 min, 49°C/45 min,……., 52°C/60 min). The seed bags were frequently stirred for uniform exposure of seeds to hot water while dipping and also to maintain uniform heat all over the tank. At the end of the treatment, seeds were taken out of hot water bath and spread on blotter paper. After that, the blotter paper with seeds was placed in shade for drying of seeds. These seeds were used for further test.

For hot air seed treatment, hot air electric oven with forced air circulation system was used which ensured even distribution of heat, consisting of double-walled insulated metallic construction for conserving heat energy and fitted with the adjustable wire mesh-plated trays or aluminum trays. Temperature was set through digital PID controller. Generally, it took 10-15 min for the machine to reach the desired temperature. After the desired temperature obtained, the seeds were kept in kraft paper bags and subjected for heating to different treatment combinations viz at 70°C for 24 h, at 70°C for 36 h,……., at 76°C for 60 h. At the end of the treatment, seeds were taken out, cooled down to normal temperature and used for further test.

For microwave seed treatment, household type IFB microwave of 900 W with energy at high power supplied by magnetron (heat generating device in microwave) operating at 2,450 MHz frequency in the continuous mode, was used to carry out the experiment. Seeds were placed in a sterilized open glassware Petri plate and subjected to different periods of exposure of 5, 10, 15, 20 and 30 sec at micro power level of 900 W. After the treatment, seeds were taken out and used for further test.

Four hundred seeds were taken for each replication and the test was carried out in 4 replications, 100 seeds each. The seeds were allowed to germinate using paper towel method at 25°C in seed germinator. The first and final count of seeds was taken at 7th and 14th day, after putting the seeds in germinator. The germination percentage test was carried out as per the ISTA guidelines (Anon 1996).

Germination percentage was calculated by using the formula given below:

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds used}} \times 100$$

The number of seedlings emerged were counted on each day from 1st to 14th day and the speed of germination was calculated using the formula given by Maguire (1962):

$$\text{Speed of germination} = n1/d1 + n2/d2 + n3/d3 + \ldots\ldots\ldots + n14/d14$$

where n = Number of germinated seeds, d = Number of days

Ten normal seedlings were selected at random from paper towel method to work out the seedling length. Total seedling length was worked out by taking the total length of seedlings from the tip of the primary leaf to the tip of primary root with the help of scale. The length of seedlings was measured on 14th day of germination test.

The same ten seedlings, selected for measuring seedling length, were used to work out seedling dry weight. Seedlings were kept in oven at 80^{o}C for 48 hours and weight was taken.

Seedling vigour index-I (SVI-I) and seedling vigour index-II (SVI-II) were calculated as per the formulae given by Abdul-Baki and Anderson (1973):

$$\text{SVI-I} = \text{Germination (\%)} \times \text{Seedling length (cm)}$$

$$\text{SVI- II} = \text{Germination (\%)} \times \text{Seedling dry weight (mg)}$$

Experiment was laid out in randomized complete block design having ten treatments comprising 3 replications. Nursery beds of 1 m × 0.5 m in size and 20 cm in height were prepared. On the second fortnight of February 2020, 200 seeds under each treatment were sown in lines about 5 cm apart and a depth of 1-2 cm.

Seeds were covered with a fine layer of well decomposed FYM and irrigated with sprinkler to maintain the optimum moisture level till the seeds germinated. The nursery beds were mulched with plastic sheets. Proper attention was given to remove the covered mulch from the nursery beds.

As and when the minute thread like structures (seedlings) were seen above the ground, mulch was removed carefully to avoid any damage to emerging seedlings. Irrigation was done with sprinkler as and when required. Hand weeding was done to remove weeds.

Total seedling emergence per replication was calculated as follows:

$$\text{Emergence (\%)} = \frac{\text{Number of seedlings emerged}}{\text{Total number of seeds used}} \times 100$$

The number of seedlings emerged was counted on each day when the emergence started and the speed of germination was calculated:

$$n1/d1 + n2/d2 + n3/d3 + \ldots\ldots\ldots + n/d$$

where n = Number of emerged seedlings, d = Number of days

Seedling height was measured from the base of the plant to the top of the main axis and recorded at weekly interval.

The incidence of various diseases like damping-off and viruses was recorded in nursery by using the formula given below:

$$\text{Disease incidence (\%)} = \frac{\text{Number of diseased seedling/plot}}{\text{Total number of seedling/plot}} \times 100$$

RESULTS and DISCUSSION

Effect of hot water seed treatment on seed quality parameters

The data on the effect of hot water treatment on seed quality parameters of bell pepper are given in Table 1.

Seed germination: The highest seed germination (89.50%) was observed in hot water treatment at 50^{o}C for 60 min followed by 49^{o}C for 60 min, 49^{o}C for 45 min and 51^{o}C for 30 min with germination of 85.00, 84.75 and 84.00 per cent respectively, the latter three being at par, and at par with control (83.25%). The germination percentage declined as the temperature of hot water treatment was increased further and lowest germination was recorded at 52^{o}C for 60 min (71.00%), 52^{o}C for 45 min (71.50%) and 52^{o}C for 30 min (72.00%), the three treatments being at par.

Speed of germination: The speed of germination ranged between 18.23 and 22.42 under different treatments and it was highest (22.42) in control and at 50^{o}C for 60 min (22.02), the two being at par. However, speed of germination in hot water treated seeds at 50^{o}C for 60 min (22.02) was also at par with that of at 49^{o}C for 60 min (21.40) and 49^{o}C for 45 min (21.25). Decrease in speed of germination was observed as the temperature increased. The lowest germination was observed at 52^{o}C for 60 min (18.23), 52^{o}C for 45 min (18.48) and 52^{o}C for 30 min (18.81), the three treatments being at par.

Seedling length: The seedling length under different treatments ranged between 8.85 and 10.80 cm.

Amongst all the treatments, higher seedling length was recorded in hot water seed treatment at 50°C for 60 min (10.80 cm), 49°C for 60 min (10.50 cm), 49°C for 45 min (10.42 cm), 49°C for 30 min (10.40 cm), 51°C for 30 min (10.30 cm), 50°C for 45 min (10.12 cm) and 50°C for 30 min (10.05 cm), all the treatments being at par with control (10.42 cm). The lower seedling length was recorded in seed treatment at 52°C for 60 min (8.85 cm), 52°C for 45 min (9.20 cm), 52°C for 30 min (9.20 cm), 51°C for 60 min (9.40 cm) and 51°C for 45 min (9.83 cm), all the treatments being at par.

Seedling dry weight: The seedling dry weight ranged between 2.06 and 2.47 mg. Seed treatment at 50°C for 60 min, 49°C for 60 min, 49°C for 45 min, 51°C for 30 min, 50°C for 30 min, 51°C for 45 min, 50°C for 45 min and 52°C for 30 min resulted in seedling dry weight of 2.47, 2.45, 2.32, 2.28, 2.27, 2.27, 2.25 and 2.25 mg respectively which was higher than all other treatments but at par with control (2.36 mg).

Seedling vigour index-I (length): Seedling vigour index-I (length) ranged between 628.35 and 966.46 under various treatments. It was recorded highest (966.46) at 50°C for 60 min and 49°C for 60 min (892.00), the two treatments being at par, in comparison to 868.07 in control. The lowest seedling vigour index-I was observed at 52°C for 60 min (628.35), 52°C for 45 min (657.70), 52°C for 30 min (661.70) and 51°C for 60 min (697.37), all the four treatments being at par.

Seedling vigour index-II (mass): The trend was similar to seedling vigour index-I in case of effect of different hot water treatments on seedling vigour index-II. The seedling vigour index-II (mass) ranged between 146.41 and 221.87. It was recorded highest (221.87) at 50°C for 60 min and 49°C for 60 min (208.91), the two treatments being at par, in comparison to 196.91 in control. The lowest seedling vigour index-I was observed at 52°C for 60 min (146.41), 52°C for 45 min (149.09), 51°C for 60 min (158.54) and 52°C for 30 min (161.97), the four treatments being at par.

Earlier, Ivey and Miller (2005) reported that bell pepper seeds are more sensitive to hot water treatment. The soaking of bell pepper seeds in hot water at appropriate temperature improved their germination rate. Hot water seed treatment has beneficial effect of priming which results in faster germination than untreated seeds. In the present study, it was observed that hot water seed treatment affected seedling length after germination. The results of the study are almost similar to that of Singh et al (2019) who observed that the hot water treated seeds of bell pepper at temperature 50-52°C for 30 min showed maximum germination, seedling length, seedling dry weight, seed vigour index-I and seed vigour index-II as compared to untreated seeds. The differences in the seedling length were observed due to the difference of temperature and duration and also due to the variation of seed coat thickness (Azad et al 2011).

Effect of hot air seed treatment on seed quality parameters

The data on the effect of hot air treatment on seed quality parameters of bell pepper are given in Table 2.

Seed germination: The germination ranged between 41.50 and 82.50 per cent under different treatments. The highest germination (82.50%) was observed in control followed by 74.00 and 72.00 per cent at 72°C for 24 h and 72°C for 36 h respectively, the latter two being at par. Lowest germination (41.50%) was observed at 76°C for 60 h.

Speed of germination: The speed of germination ranged between 16.47 and 26.34. The highest speed of germination (26.34) was recorded in control followed by at 72°C for 24 h (24.37), 72°C for 36 h (24.02), 74°C for 48 h (24.00) and 72°C for 48 h (23.78), the latter four treatments being statistically at par. The lowest speed of germination was recorded at 76°C for 60 h (16.47) and 76°C for 48 h (16.74), the two being at par.

Seedling length: The seedling length ranged between 8.27 and 10.48 cm. Amongst all the treatments, the highest seedling length (10.48 cm) was recorded in control which was at par with seed treatment at 72°C for 24 h (10.43 cm). The lowest seedling length was recorded in seed treatment at 76°C for 60 h (8.27 cm) and at 70°C for 60 h (8.29 cm), the two treatments being at par.

Seedling dry weight: The seedling dry weight ranged between 1.75 and 2.36 mg. Highest seedling dry weight (2.36 mg) was recorded in control followed by seed treatment at 72°C for 24 h (2.15 mg), 72°C for 36 h (2.12 mg), 72°C for 48 h (2.12 mg), 74°C for 48 h (2.11 mg) and 72°C for 60 h (2.10 mg), the latter five treatments being at par. The lowest seedling dry weight was observed at 76°C for 60 h (1.75 mg).

Table 1. Effect of different hot water seed treatments in bell pepper on seed quality parameters under in vitro condition

Hot water treatment	Seed quality parameters					
	Germination (%)	Speed of germination	Seedling length (cm)	Seedling dry weight (mg)	SVI-I (length)	SVI-II (mass)
49°C/30 min	82.75 (9.15)	19.62	10.40	2.07	858.50	171.44
49°C/45 min	84.75 (9.26)	21.25	10.42	2.32	883.57	196.69
49°C/60 min	85.00 (9.27)	21.40	10.50	2.45	892.00	208.91
50°C/30 min	81.00 (9.05)	19.15	10.05	2.27	814.30	184.12
50°C/45 min	82.00 (9.11)	19.45	10.12	2.25	829.95	185.13
50°C/60 min	89.50 (9.51)	22.02	10.80	2.47	966.47	221.87
51°C/30 min	84.00 (9.21)	21.15	10.30	2.28	865.57	191.75
51°C/45 min	76.25 (8.78)	19.28	9.83	2.27	750.42	173.48
51°C/60 min	74.25 (8.67)	19.08	9.40	2.13	697.37	158.54
52°C/30 min	72.00 (8.54)	18.81	9.20	2.25	661.70	161.97
52°C/45 min	71.50 (8.51)	18.48	9.20	2.08	657.70	149.09
52°C/60 min	71.00 (8.48)	18.23	8.85	2.06	628.35	146.41
Control	83.25 (9.17)	22.42	10.42	2.36	868.07	196.91
$CD_{0.05}$	0.10	0.83	0.98	0.23	79.09	19.94

Figures in parentheses are square root transformed values

Table 2. Effect of different hot air seed treatments in bell pepper on seed quality parameters under in vitro condition

Hot air treatment	Seed quality parameters					
	Germination (%)	Speed of germination	Seedling length (cm)	Seedling dry weight (mg)	SVI-I (length)	SVI-II (mass)
70°C/24 h	68.50 (55.83)	23.56	9.25	1.97	633.96	135.45
70°C/36 h	66.75 (54.76)	23.35	9.24	1.97	616.76	131.83
70°C/48 h	66.00 (54.31)	22.10	8.51	1.83	562.81	121.11
70°C/60 h	63.75 (52.96)	19.60	8.29	1.85	530.21	117.93
72°C/24 h	74.00 (59.32)	24.37	10.43	2.15	769.25	159.46
72°C/36 h	72.00 (58.03)	24.02	10.28	2.12	741.47	152.46
72°C/48 h	63.50 (52.86)	23.78	10.08	2.12	638.19	135.13
72°C/60 h	60.25 (50.89)	21.16	9.61	2.10	578.74	126.52
74°C/24 h	65.75 (54.16)	20.90	9.98	2.04	656.63	134.46
74°C/36 h	63.25 (52.66)	19.40	9.51	2.06	601.37	130.45
74°C/48 h	70.00 (56.76)	24.00	10.09	2.11	706.66	147.87
74°C/60 h	51.50 (45.84)	17.63	9.32	1.95	480.83	100.82
76°C/24 h	55.25 (47.99)	21.46	9.54	1.95	527.63	108.15
76°C/36 h	50.75 (45.41)	20.63	9.08	1.88	461.74	95.70
76°C/48 h	45.00 (42.11)	16.74	8.85	1.95	397.17	87.75
76°C/60 h	41.50 (40.09)	16.47	8.27	1.75	343.50	72.93
Control	82.50 (65.24)	26.34	10.48	2.36	863.73	195.11
$CD_{0.05}$	1.57	0.70	0.14	0.05	24.65	6.73

Figures in parentheses are angular transformed values

Seed vigour index-I (length): The seed vigour index-I (length) ranged between 343.50 and 863.73. It was recorded highest (863.73) in control followed by 769.25 in seed treatment at 72°C for 24 h. The lowest seed vigour index-I (length) (343.50) was observed in seed treatment at 76°C for 60 h.

Seed vigour index-II (mass): The trend was similar to seed vigour index-I (length) in case of effect of different hot air treatments on seed vigour index-II (mass). It ranged between 72.93 and 195.11. It was recorded highest (195.11) in control followed by seed treatment at 72°C for 24 h (159.46) and the lowest was recorded in case of seed treatment at 76°C for 60 h (72.93).

The germination of seeds gradually got reduced with increased temperature and duration which might be due to the reason that the loss in seed quality attributed to internal injury caused to seed during rapid drying and excessive stretching of cell membrane resulting in loss of integrity of seed coat.

At high temperature, the rapid evaporation of moisture from the surface of seeds might cause extreme moisture stress that might have damaged embryo and reduced the germination of seeds. Seeds with high moisture content may suffer more severe damage as compared to seeds with lower moisture content by hot air seed treatment (Nakumura 1982).

Seed germination in bell pepper was lowest by the hot air seed treatment at 76°C for 60 h. The germination and germination energy in seed decreases as the hot air treatment temperature and duration increase (Shiomi 1992). The author reported that when the cabbage seeds were subjected to 65 and 70°C for 7 days, the germination decreased to the level of 85 and 82 per cent respectively.

It is extrapolated from the data that seeds treated with different temperatures and time when subjected to blotter method showed significant differences among one another wrt seedling length, seedling dry weight and seed vigour index-I (length) and seed vigour index-II (mass). It was found that hot air seed treatment affected seedling length after germination.

In the present study, the germination percentage was significantly decreased which was accompanied by a reduction in seed vigour index-I and seed vigour index-II. Seeds with high moisture content may suffer more severe damage as compared to seeds with lower moisture content by hot air seed treatment (Nakumura 1982).

Effect of microwave seed treatment on seed quality parameters

The data on the effect of microwave seed treatment on seed quality parameters of bell pepper are given in Table 3.

Seed germination: The germination percentage differed among the treatments. The highest germination (91.25 and 90.00%) was observed in seed exposure in microwave for 5 and 10 sec respectively, the two treatments being at par, as compared to 84.75 per cent in control. As exposure duration increased, seed germination decreased and the lowest germination was noticed in seed exposure in microwave for 30 sec (68.25%).

Speed of germination: The speed of germination ranged between 24.16 and 27.32. The seeds exposed in the microwave for 5, 10 and 15 sec recorded highest speed of germination (27.32, 26.91 and 26.10 respectively) which was at par with that of control (26.34). There was a decrease in speed of germination observed as the period of exposure increased. The lowest germination was observed in 30 (24.16) and 20 (24.80) sec exposure, the two treatments being at par. Increase in exposure time increased seed temperature and as the radiation exposure exceeded above 15 sec, slight decrease in the germination percentage and seed vigour was observed.

Seedling length: The seedling length ranged between 9.42 to 11.95 cm. Amongst all the treatments, the highest seedling length was recorded in microwave exposure of 5 (11.95 cm), 15 (11.76 cm) and 10 (11.75 cm) sec which was at par with control (11.40 cm). The lowest seedling length was observed in 30 (9.42 cm) and 20 (10.02 cm) sec exposure time, the two treatments being at par.

Seedling dry weight: Significant differences in seedling dry weight were observed among different treatments. The seedling dry weight ranged between 1.72 and 2.39 mg. Seeds exposed for 5, 10 and 15 sec resulted in highest seedling dry weight (2.39, 2.38 and 2.37 mg respectively) which was at par with control

(2.36 mg). The lowest seedling dry weight was recorded in 30 sec exposure (1.72 mg).

Seed vigour index-I (length): The seed vigour index-I (length) ranged between 641.47 and 1,092.83. It was highest (1,092.83 and 1,057.73) in 5 and 10 sec exposure respectively, in comparison to control (883.67). The lowest seed vigour index-I (641.47) was observed in 30 sec exposure.

Seedling vigour index-II (mass): The trend was similar to seed vigour index-I (length) in case of seedling vigour index-II (mass). It ranged between 117.46 and 218.33. It was recorded highest (218.33 and 214.20) in 5 and 10 sec exposure respectively, the two being at par, in contrast to 200.29 in control. The lowest seed vigour index-II (117.46) was observed in 30 sec exposure.

Effect of thermophysical seed treatments in bell pepper on seedling emergence, speed of germination and seedling height under nursery condition

The three best treatments on the basis of performance under in vitro study from each category viz hot water seed treatment (49°C/45 min, 49°C/60 min and 50°C/60 min), hot air seed treatment (72°C/24 h, 72°C/36 h and 74°C/48 h) and microwave seed treatment (5, 10 and 15 sec) along with untreated (control) were used for nursery raising. The data on

Table 3. Effect of different microwave seed treatments in bell pepper on seed quality parameters under in vitro condition

Microwave exposure time (sec)	Seed quality parameters					
	Germination (%)	Speed of germination	Seedling length (cm)	Seedling dry weight (mg)	SVI-I (length)	SVI-II (mass)
5	91.25 (72.28)	27.32	11.95	2.39	1,092.83	218.33
10	90.00 (71.54)	26.91	11.75	2.38	1,057.73	214.20
15	87.00 (68.83)	26.10	11.76	2.37	1,023.34	206.40
20	77.50 (60.31)	24.80	10.02	2.10	756.37	158.81
30	68.25 (55.69)	24.16	9.42	1.72	641.47	117.46
Control	84.75 (67.03)	26.34	11.40	2.36	883.67	200.29
$CD_{0.05}$	1.82	1.25	0.87	0.12	60.77	10.82

Figures in parentheses are angular transformed values

Table 4. Effect of thermophysical seed treatments in bell pepper on seedling emergence, speed of germination and seedling height under nursery condition

Treatment	Total emergence (%)	Speed of germination	Seedling height (cm) after days of sowing		
			28	35	42
T_1: Hot water 49°C/45 min	74.67 (59.75)	75.33	4.25	6.48	10.10
T_2: Hot water 49°C/60 min	80.33 (63.65)	76.67	4.49	7.25	11.00
T_3: Hot water 50°C/60 min	85.16 (67.32)	78.20	4.51	7.27	11.20
T_4: Hot air 72°C/24 h	72.33 (58.24)	72.19	4.21	6.44	10.16
T_5: Hot air 72°C/36 h	68.83 (56.04)	70.28	4.18	6.42	9.76
T_6: Hot air 74°C/48 h	65.33 (53.90)	67.30	4.16	6.24	9.46
T_7: Microwave 5 sec	84.00 (66.39)	75.58	4.57	7.48	11.40
$T_{8:}$ Microwave 10 sec	80.33 (63.66)	73.97	4.46	7.26	10.80
T_9: Microwave 15 sec	77.33 (61.54)	70.52	4.33	7.16	9.80
T_0: Control	71.33 (57.60)	74.56	4.22	6.50	9.86
$CD_{0.05}$	1.16	2.36	0.09	0.21	0.25

Figures in parentheses are angular transformed values

the effect of thermophysical seed treatments in bell pepper on seedling emergence, speed of germination and seedling height under nursery condition are given in Table 4.

Seed emergence: The total seed emergence varied from 65.33 to 85.16 per cent in different treatments. Maximum emergence of 85.16 and 84.00 per cent was recorded in treatment T_3 (Hot water seed treatment at 50°C for 60 min) and T_7 (Microwave seed treatment for 5 sec) respectively, the two being at par, in comparison to 71.33 per cent in control and lowest (65.33%) in T_6 (Hot air treatment at 74°C for 48 h).

Speed of germination: The thermophysical treatment of seeds had a significant effect on speed of germination in bell pepper in the nursery. It ranged between 67.30 and 78.20. The highest speed of germination of 78.20 and 76.67 was recorded in T_3 (Hot water seed treatment at 50°C for 60 min) and T_2 (Hot water seed treatment at 49°C for 60 min) respectively, which was at par, in contrast to 74.56 in control. The lowest speed of germination (67.30) was recorded in T_6 (Hot air seed treatment at 74°C for 48 h).

Seedling height: After 28 days of sowing, seedling height was maximum in case of T_7 (microwave seed treatment for 5 sec) (4.57 cm), T_3 (Hot water seed treatment at 50°C for 60 min) (4.51 cm) and T_2 (Hot water seed treatment at 49°C for 60 min) (4.49 cm), the three treatments being at par. The minimum seedling height was observed in T_6 (Hot air seed treatment at 74°C for 48 h) (4.16 cm), T_5 (Hot air seed treatment at 72°C for 36 h) (4.18 cm), T_4 (Hot air seed treatment at 72°C for 24 h) (4.21 cm), T_0 (Control) (4.22 cm) and T_1 (Hot water seed treatment at 49°C for 45 min) (4.25 cm), all the treatments being at par. After 35 days of sowing, maximum seedling height was recorded in T_7 (Microwave seed treatment for 5 sec) (7.48 cm) and T_3 (Hot water seed treatment at 50°C for 60 min) (7.27 cm), the two treatments being at par, as against 6.50 cm in T_0 (Control).

The lowest seedling height was observed in T_6 (Hot air seed treatment at 74°C for 48 h) (6.24 cm), T_5 (Hot air seed treatment at 72°C for 36 h) (6.42 cm), and T_4 (Hot air seed treatment at 72°C for 24 h) (6.44 cm), the three treatments being at par. In case of 42 days after sowing, seedling height was maximum in case of T_7 (Microwave seed treatment for 5 sec) (11.40 cm) and T_3 (Hot water seed treatment at 50°C for 60 min) (11.20 cm), the two being at par, as against 9.86 cm in T_0 (Control). Lowest seedling height (9.46 cm) was observed in T_6 (Hot air seed treatment at 74°C for 48 h).

Among all the treatments used, hot water seed treatment at 50°C for 60 min was among the most superior treatments which resulted in maximum total emergence, speed of germination and seedling height. Singh et al (2019) reported that hot water treatment at 50-52°C for 30 min showed maximum seedling emergence than other treatments and control in bell pepper crop.

Table 5. Effect of thermophysical seed treatment on disease incidence in bell pepper under nursery condition

Treatment	Component		
	Ungerminated seeds (%)**	Damping-off (post-emergence) (%)*	Virus (%)*
T_1: Hot water 49°C /45 min	25.33 (30.20)	8.88 (3.14)	8.88 (3.14)
T_2: Hot water 49°C /60 min	19.67 (26.31)	8.05 (3.00)	6.94 (2.81)
T_3: Hot water 50°C /60 min	14.84 (22.63)	6.94 (2.81)	5.00 (2.44)
T_4: Hot air 72°C/24 h	27.67 (31.72)	9.44 (3.23)	8.05 (3.00)
T_5: Hot air 72°C /36 h	31.16 (33.92)	11.10 (3.47)	5.83 (2.61)
T_6: Hot air 74°C /48 h	34.67 (36.05)	11.94 (3.59)	4.44 (2.33)
T_7: Microwave 5 sec	16.00 (23.56)	12.76 (3.71)	11.37 (3.51)
T_8: Microwave 10 sec	19.67 (26.30)	14.99 (3.99)	10.25 (3.35)
T_9: Microwave 15 sec	22.67 (28.41)	16.38 (4.16)	9.16 (3.18)
T_0: Control	28.67 (32.35)	24.44 (5.04)	17.77 (4.33)
$CD_{0.05}$	1.16	0.14	0.20

*Figures in parentheses are square root transformed values, **Figures in parentheses are angular transformed values

Effect of thermophysical seed treatments on disease incidence in bell pepper under nursery condition

Table 5 depicts the effect of thermophysical seed treatment on disease incidence in bell pepper under nursery condition.

Ungerminated seeds: Significantly maximum ungerminated seeds (34.67%) were recorded in T_6 (Hot air seed treatment at 74°C for 48 h) and minimum (14.84%) in T_3 (Hot water seed treatment at 50°C for 60 min) and T_7 (Microwave treatment for 5 sec) with 16.00 per cent, the two treatments being at par, as against 28.67 per cent in T_0 (Control).

Disease incidence: The incidence of post-emergence damping-off of seedlings was highest in T_0 (Control) (24.44%) followed by T_9 (Microwave seed treatment for 15 sec) (16.38%) and T_8 (Microwave seed treatment for 10 sec) (14.99%) and lowest in T_3 (Hot water seed treatment at 50°C for 60 min) (6.94%) followed by T_2 (Hot water seed treatment at 49°C for 60 min) (8.05%). Highest virus infection (17.77%) was observed in T_0 (Control) followed by T_7 (Microwave seed treatment for 5 sec) (11.37%) and T_8 (Microwave seed treatment for 10 sec) (10.25%), the two treatment being at par and lowest in T_6 (Hot air seed treatment at 74°C for 48 h) (4.44) and T_3 (Hot water seed treatment at 50°C for 60 min) (5.00%), the latter two treatments being at par.

Thermophysical seed treatment has been used to control many seed borne pathogens by applying temperature hot enough to kill pathogens but not so hot and lethal to kill the seed.

Hot water temperature 50-53°C has been found as optimum range for reducing various seed borne diseases including fungi (Walker 1923) and viruses (Nega et al 2003) of vegetable crops. Hot air treatment method can completely eradicate the seed borne fungal as well as viral pathogens (Kim and Lee 2000). The mode of action of thermophysical seed treatment can be applied for direct killing of seed borne pathogens in and on the seed.

CONCLUSION

In bell pepper cv Solan Bharpur, hot water seed treatment at 50°C for 60 min as well as microwave seed treatment for 5 sec proved most effective in among all the treatments used. Hot water seed treatment at 50°C for 60 minutes also reduced the incidence/severity of damping-off to the maximum. The two treatments viz hot air seed treatment at 74°C for 48 h and hot water seed treatment at 50°C for 60 min were found most effective in reducing the incidence of viral diseases.

REFERENCES

Abdul-Baki AA and Anderson JD 1973. Vigour determination in soybean seed by multiple criteria. Crop Science **13(6):** 630-633.

Anonymous 1996. International rules for seed testing 1996. International Seed Testing Association, Richtiarkade, Wallisellen.

Azad S, Manik MR, Hasan S and Matin MA 2011. Effect of different pre-sowing treatments on seed germination percentage and growth performance of *Acacia auriculiformis*. Journal of Forestry Research **22(2):** 183-188.

Ivey LLM and Miller SA 2005. Evaluation of hot water seed treatment for the control of bacterial leaf spot and bacterial canker on fresh market and processing tomatoes. Acta Horticulturae **695:** 197-204.

Kim DH and Lee JM 2000. Seed treatment for cucumber green mottle mosaic virus (CGMMV) in gourd (*Lagenaria siceraria*) seeds and its detection. Journal of Korean Society of Horticultural Science **41(1):** 1-6.

Maguire JD 1962. Speed of germination – aid selection and evaluation for seedling emergence and vigor. Crop Science **2(2):** 176-177.

Nakamura H 1982. Effects of dry heat treatment for seed disinfection on germination in vegetables. Japan Agricultural Research Quarterly **15(4):** 243-247.

Nega E, Ulrich R, Werner S and Jahn M 2003. Hot water treatment of vegetable seed – an alternative seed treatment method to control seed-borne pathogens in organic farming. Journal of Plant Diseases and Protection **110(3):** 220-234.

Shiomi T 1992. Black rot of cabbage seeds and its disinfection under a hot-air treatment. Japan Agricultural Research Quarterly **26(1):** 13-18.

Singh S, Bharat NK, Singh H, Kumar S, Jakhar S and Vijay 2019. Effect of hot water treatment of seeds on seed quality parameters and seedling growth parameters in bell pepper (*Capsicum annuum*). Indian Journal of Agricultural Sciences **89(1):** 133-137.

Walker JC 1923. The hot water treatment of cabbage seed. Phytopathology **13:** 251-253.