The Effect of Microwave Treatment on Germination, Vigour and Health of China Aster (*Callistephus chinensis* Nees.) Seeds

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Abstract

The purpose of this research was to study effects of microwave treatment on China aster seed germination, vigour and infestation with fungi, at temperature 20°C. The seeds were treated in microwave oven (power 850 W heating power) in dry conditions and in water for 10, 20, 30, 40, 50, 60, 90, 120 and 180 s respectively.

Keywords: China aster seeds, Microwave treatment, Germination, Vigour, Health

1. Introduction and literature review

With the development of the flower industry, some producers have been doing research, answering the question: how to develop the new varieties and how to improve the quality of flower seeds? The most important problems are that flower seed retaining some characteristics typical for wild species such as dormancy and wide range of seed maturity at harvest. Another important problem is that some flower seeds can be easy to infect with seed-borne pathogens. Seed treatment is a common method used to improve seed quality, because is convenient, cheap and effective, it is accepted by seed producers widely.

Callistephus chinensis Nees. is more commonly known as China aster. The family has an estimated 1,150 genera and a huge number of species seen almost all over the world originating from North America, Europe, China, etc. All those varieties are divided into four main groups: needle group, peony group, chrysanthemum group and prince group. Native to Asia, this lovely flowering annual is worth the little extra effort it takes for growing. Most species of aster are perennial and generally bloom in August. They have daisy-like or star-like flower heads (4-6 cm in diameter) with a yellow center on leafy, often tall, stems. Their colors vary from white to creamy yellow, pink, blue, red and purple. They do well in beds, borders or pots and are a favorite as cut flowers because of their longevity.

The color of China aster seeds is bright brown. Seed length, width and thickness are 3.0-5.0 mm, 1.5-2.0 and 0.3-1.2 mm respectively. There are 400-500 seeds in 1 gram (Duczmal and Tucholska, 1993).

Generally, quality of China aster seed is very poor. Germination capacity standard before the Poland joint the European Union in 2004 for this species was only 45% (Anonymous, 1990). Grzesik et al. (1998) found that the mature China aster seeds harvested in late autumn were lighter than those collected in early autumn. Seeds collected from tertiary capitula germinated worse than those collected from primary or secondary capitula.

Zhang (1997) reported that in one of the examined China aster varieties the percentage of dead seed was very high, amounted to 30%.

Orlicz-Luthardt (1998) reported, after mycological analysis of manual harvested China aster seeds, that dominant fungi contaminated seed coat. The main detected fungi were as follow: *A. alternata*, *Cephalosporium* sp., *Penicillium* spp., *Sclerotinia sclerotiorum* (Lib.) de Bary, *Trichothecium roseum* Link Fries, *B. cinerea* and *Fusarium oxysporum*.

In order to improve the quality of China aster seeds, many methods of seed treatment had been studied. Improvement of germination by conditioning (priming) of seeds in water has been known for many years (Lang, 1965). Several methods are used for seed conditioning in order to accelerate the rate of germination and to improve seedling uniformity. These methods can be classified as biological, chemical and physical.

Priming and fungicide treatments are the most popular methods improving quality of China aster seeds.

2. Materials and methods

2.1 Materials

2.1.1 Seeds

One commercial sample of China aster (Callistephus chinensis Nees.) seeds obtained from CNOS Horticultural Seed Company Ltd in Poznan was used in the study.

2.1.2 Fungicide

Kaptan Zawiesinowy 50 WP (a.i. captan, 50%) was used in the experiment. The fungicide was produced by Zakłady Chemiczne „Organika-Azot" SA in Jaworzno.

2.2 Methods

2.2.1 Seed treatment

2.2.1.1 Fungicide treatment

Seeds were soaked in 0.4% solution of Kaptan Zawiesinowy 50 WP for 30 min. After the treatment seeds were surface dried between blotters.

2.2.1.2 Dry microwave treatment

1g of China aster seeds at a time was placed evenly in an open glass Petri dish and subsequently the dish was placed in the center of plate in an Ignis AKL-560 microwave oven at full strength 850 W, for 10, 20, 30, 40, 50, 60, 90, 120 and 180 s.

2.2.1.3 Seed microwave treatment in water

1g Seeds were wrapped in cotton scarf and placed in Pyrex glass beakers containing 500 ml of distill-water. The beaker with seeds was placed in the center of rotating plate in an Ignis AKL-560 microwave oven of a full power 850 W, for 10, 20, 30, 40, 50, 60, 90, 120 and 180 s.

After treatment seeds were chilled instantly in Pyrex glass beakers containing cold water and subsequently chilling under cold tap water for 2 min. After chilling seeds were taken out from the scarf and dried back in plastic trays lined with blotter paper at 20°C and 45% relative humidity for 48 h to equilibrium moisture content.

2.2.2 Seed quality assessment

The germination, vigour and health tests of China aster seeds were performed for:

a) untreated seeds (control I)

b) seeds treated with fungicide (control II)

c) dry microwave treated seeds

d) seeds microwave treated in water

2.2.2.1 Germination test

The germination test was conducted at 20°C in darkness on 6 replicates of 50 seeds. Seeds were placed in 9 cm diameter Petri dishes containing 6 layers of blotting paper wetted with distilled water. Moreover, after 6 and 12 days of germination, normal seedlings were evaluated according to ISTA Rules (ISTA, 1996). The seeds were incubated at 20°C in darkness. The percentage of normal seedlings at first count (I count) and final count (II count) presents germination capacity. Furthermore, after 12 days, abnormal seedlings, dead seeds and fresh ungerminated seeds were distinguished.

Additionally the total number of germinating seeds (maximum germination – Gmax) was evaluated using statistical program Seed Calculator 2.1 (Yalink and Van der Schoor,1999).

2.2.2.2 Vigour test

The vigour test was conducted at 20°C in darkness on 6 replicates of 50 seeds for each treatment. Seeds were placed in 9 cm diameter Petri dishes containing 6 layers of blotting paper wetted with distilled water. Seeds were considered as germination when there was a visible protrusion through the seed coat. The seeds were incubated under the same conditions like in the previous test. Germinating seeds were counted daily and removed from Petri dishes until no new germinating seeds occurred.

The following parameters were calculated using statistical program Seed Calculator 2.1 (Yalink and Van der Schoor, 1999):

- T_1 – time to 1% of Gmax
- T_{10} – time to 10% of Gmax
- T_{25} – time to 25% of Gmax
- T_{50} – time to 50% of Gmax
- T_{75} – time to 75% of Gmax
- T_{90} – time to 90% of Gmax
- MGT – mean germination time
- Uniformity I (U_{75-25}) – time between 25 and 75% of Gmax
- Uniformity II (U_{90-10}) – time between 90 and 10% of Gmax

2.2.2.3 Health test

Two hundred seeds from each treatment were placed on the surface of the 9 cm diameter Petri dishes, 20 seeds per dish, containing 6 layers of blotting paper wetted with distilled water. The seeds were incubated at 20°C for 24 h in darkness, next at -20ºC for 24 h and then at 20ºC for 8 days, under alternating cycle 12 h of near ultra violet light and 12 h darkness. After incubation each seed was examined thoroughly and the fungi were identified based on their habit and spore character by using a stereomicroscope and compound microscope, respectively (Agrios, 2005, Barnett and Hunter, 1987, Cappelli and Covarelli, 2005, Ellis, 1971, Malone and Muskett, 1964). A total number of seeds free from fungi for each treatment were counted.

2.2.2.4 Moisture content

For untreated and dry microwave treated seeds moisture contents were evaluated. Seed – 4 replicates per 0.5 g – were dried at 130°C for 1 h.

The seed moisture content was counted according to:

$W= [(a-b) / (a-c)] \cdot 100\%$

where:

a – is the weight of container with seeds before drying,

b – is the weight of container with seeds after drying,

c – is the weight of container.

2.2.3 Statistical analysis

Seed Calculator 2.1 software developed by Plant Research International in Wageningen in the Netherlands was applied to analyze total number of germinating seeds and vigour parameters (Yalink and Van der Schoor, 1999).

Germination, vigour and health data were analyzed by means of variance analysis (ANOVA) followed by Duncan's multiple range test. Percentage was transformed according to:

Y=arc sin [sqr (x/100)] before ANOVA.

3. Results

3.1 Seed germination

For untreated seeds the high percentage of maximum germination (total number of germinating seeds) was noted (Tab. 1). Dry microwave seed treatment for time longer than 20 s, as well as treating seeds in water for 30, 60, 90, 120 and 180 s, and fungicide treatment, resulted in significant decrease of this parameter. Moreover, after seed treatment in dry condition for 120 and 180 s and in water for 180 s, seeds did not germinate. Germination capacity at first count decreased significantly after dry microwave seed treatment for 40, 50, 60 and 180 s, microwave seed treatment in water for 10, 90, 120 and 180 s, and after fungicide treatment.

For untreated seeds the percentage of abnormal seedling amounted to 5.3% was noted (Tab. 2). Dry microwave seed treatment for 120 s, as well as treating seeds in water for 30 s, resulted in significant increase of this parameter. However, after seed treatment in dry condition and in water for 180 s, the percentage of abnormal seedlings significantly decreased because the seeds did not germinate. For untreated seeds the percentage of dead seeds was 21.7%. In general, dry microwave seed treatment for time longer than 30 s, as well as treating seeds in water for 180 s, negatively affected this parameter. The number of dead seeds significantly decreased after fungicide treatment and treating seeds in water for 30 s. For untreated seeds the percentage of fresh ungerminated seeds amounted to 2.7%. Dry microwave seed treatment for 20, 60, 120, 180 s, as well as treating

seeds in water for 10, 30, 50, 60, 90, 120 and 180 s and treating seeds with Kaptan Zawiesinowy 50 WP, resulted in significant increase of this parameter (Tab. 2).

3.2 Seed vigour

The results obtained varied depending on the treatment methods. After treatment longer than 90 s and 120 s for dry treatment and treatment in water, respectively, germination did not occurre (Tab. 3, 4 and 5). T1 and T10 values were not significantly different after both fungicide and microwave treatment than in control (Tab. 3). Fungicide treatment significantly affected speed and uniformity of germination. Treating seeds with Kaptan Zawiesinowy 50 WP had negative effect on T25, T50, T75, T90, MGT and U90-10 values (Tab. 3, 4 and 5). T25 values were not significantly different after fungicide and both microwave treatments than in control except the treatment for 120 s in water, after witch the parameter increase significantly (Tab. 3). After dry treatment for 60 s and treatment in water for 120 s, as well as after fungicide treatment, the T50 value increase significantly (Tab. 4). T75, T90 and MGT values increase significantly after dry microwave seed treatment for 30, 40, 60 and 90 s, after microwave seed treatment in water for 120 s and after fungicide treatment (Tab. 4 and 5). U75-25 value increase significantly after dry microwave seed treatment for 40, 60 and 90 s, microwave seed treatment in water for 120 s and after fungicide treatment (Tab. 5). U90-10 value increase significantly after dry microwave seed treatment for 30, 40 and 90 s, microwave seed treatment in water for 120 s and after fungicide treatment (Tab. 5).

Other variants of seed treatment were not statistically different from control (Tab. 3, 4 and 5).

3.3 Mycological analysis

The following fungi were identified in tested seeds: Alternaria alternata (Fr.) Keissler, Cladosporium spp., Curvularia sp., Epicoccum purpurascens Ehrenb. ex Schlecht., Mucor sp, Penicillium spp., Phoma sp., Rhizopus nigricans Ehrenb. ex Corda and Ulocladium spp. Among them A. alternata, Cladosporium spp. and Penicillium spp. were occurred most frequently (Tab. 6). After fungicide treatment the number of seeds infested with A. alternata decreased from 39.0% to 9.5%. Microwave treatment in dry condition for 120 and 180 s, and in water for 60 s and longer, significantly decreased seeds infestation with this pathogen too. Dry microwave treatment for 20, 40 and 180 s and microwave seed treatment in water for 20, 50 and 120 s eliminated completely seed infestation with Cladosporium spp. The number of seeds infested with these fungi also decreased significantly when seeds were treated with fungicide, treated with microwave in dry condition for 30 s and microwave treated in water for 40 and 90 s. Meanwhile, number of seeds infested with fungi belonging to Penicillium genera increased significantly when seeds were treated for 50 s in dry condition and 10 s in water (Tab. 6). No differences in levels of seeds infestation with Epicoccum purpurascens and Mucor sp. were observed opposite of treatment used. The number of seeds infested with Rhizopus nigricans increase after dry microwave seed treatment for 60 s (Tab. 7). Fungi Curvularia sp. and Ulocladium spp. were not noted in untreated seeds. Dry microwave treatment for 60 s resulted in 2.0% infestation of seeds with Curvularia sp. The same treatment for 10, 20, 30 and 50 s increase significantly seed infestation with Ulocladium spp. (Tab. 8).

The tested sample was characterised with high percentage of seeds free from fungi, amounted to 53.3% Moreover, dry seed microwave treatment for 120 and 180 s, microwave treatment in water for 90, 120, 180 s and fungicide treatment resulted in significant increase of number of seeds free from fungi (Tab. 8).

3.4 Seed moisture content

Moisture content analyses were performed for untreated seeds and dry microwave treated seeds. Untreated seeds showed highest moisture content, at the level of 6.60%. Prolongation of exposition time after dry microwave seed treatment caused decrease of seed moisture content from 6.48% to 4.70% after 10 s and 180 s treatment, respectively.

4. Conclusions

1. Treating seeds in dry condition for 120 and 180 s and in water for 180 s, resulted in loss of seed viability.

2. Dry microwave seed treatment for time longer than 20 s negatively influenced total number of germinating seeds. Seeds treated in water maintain high values of maximum germination up to 90 s of exposition.

3. In general, microwave treatment had no positive effect on seed vigour. Sometimes even prolong germination and negatively affected uniformity of germination, especially after treatment in dry conditions.

4. Treating seeds with Kaptan Zawiesinowy 50 WP control seed infestation with fungi most effectively then both microwave seed treatments, however, negatively influenced mean germination time and uniformity of

germination.

5. Except *Alternaria alternata* other fungi infested the seeds in a small extent.

6. Microwave China aster seed treatment in water for 60 s significantly decreased the number of seeds infested with *A. alternata*, without negative effect on germination capacity.

Along with prolongation of the time of dry microwave treatment decrease of seed moisture content was observed.

5. Summary

The purpose of this research was to study effects of microwave treatment on China aster seed germination, vigour and infestation with fungi, at temperature 20°C. The seeds were treated in microwave oven (power 850 W heating power) in dry conditions and in water for 10, 20, 30, 40, 50, 60, 90, 120 and 180 s respectively.

The germination, vigour and health tests of China aster seeds were performed for: untreated seeds, seeds treated with 0.4% solution of Kaptan Zawiesinowy 50 WP for 30 min, dry microwave treated seeds and seeds treated in water. Additionally for untreated seeds and dry treated seeds moisture content was determined.

Treating seeds in dry condition for 120 and 180 s and in water for 180 s, resulted in loss of seed viability. Dry microwave seed treatment for time longer than 20 s negatively influenced total number of germinating seeds. Seeds treated in water maintain high values of maximum germination up to 90 s of exposition. In general, microwave treatment had no positive effect on seed vigour. Sometimes even prolonged germination and negatively affected uniformity of germination, especially after treatment in dry conditions. Treating seeds with Kaptan Zawiesinowy 50 WP control seed infestation with fungi most effectively then both microwave seed treatments, however, negatively influenced mean germination time and uniformity of germination.

Except *Alternaria alternata* other fungi infested the seeds in a small extent. Microwave China aster seed treatment in water for 60 s significantly decreased the number of seeds infested with *A. alternata*, without negative effect on germination capacity.

Along with prolongation of the time of dry microwave treatment decrease of seed moisture content was observed.

References

Anonymous. (1990). Materiał siewny. *Nasiona roślin kwiaciarskich Norma Branżowa* BN-90/9117-01. Polski Komitet Normalizacyjny, Warszawa.

Badek, B., van Duijn, B. & Grzesik, M. (2007). Effects of water supply methods and incubation on germination of China aster (*Callistephus chinensis*) seeds. *Seed Science and Technology*, 35 (3): 569-576.

Burth, U., Gaber, K., Jahn, M., Lindner, K., Motte, G., Panzer, S., Pflaumbaum, J. & Scholze, F. (1991). Seed treatment with electron beams - a new method for the control of seedborne pathogens on winter wheat. *Nachrichtenblatt des Deutschen Pflanzenschutzdienstes*, 43: 41-45.

Barnett, H. L. & Hunter, B. B. (1987). *Illustrated Genera of Imperfect Fungi*. Fourth Edition. Macmillan Publishing Company, New York, Collier Macmillan Publishers, London.

Cook, R. J. (1993). Making greater use of introduced microorganisms for biological control of plant pathogens. *Annual Review of Phytopathology*, 31: 53-151.

Duczmal, K. W. & Tucholska, H. (1993). *Nasiennictwo ogrodnicze*. Vol. I and II. Wydawnictwa Dydaktyczne Akademii Rolniczej w Poznaniu.

Ellis, M. B. (1971). *Dematiaceous Hyphomycetes*. CAB, Commonwealth Mycological Institute, Kew, Surrey, England.

Grzesik, M., Górnik, K. & Chojnowski, M. G. (1998). Effect of harvest time on the quality of *Callistephus chinensis* Nees. cv. Aleksandra seeds collected from different parts of plant. *Seed Science and Technology*, 26: 131-140.

Grzesik, M., Dawidowicz-Grzegorzewska, A. & Górnik, K. (2000). Effects of matriconditioning with Micro-Cel-E of *Callistephus chinensis* L. seeds on germination, seedling emergence, stress tolerance and some metabolic events. ISHS Acta Horticulturae 517, XXV International Horticultural Congress, Part 7: Quality of Horticultural Products. [Online] Available: http://www.actahort.org/books/517/517_14.htm.

Harman, G. E. & Nelson, E. B. (1994). Mechanisms of protection of seed and seedlings by biological seed treatments: implications for practical disease control. In: Seed Treatment: Progress and Prospects, Mono. 57,

BCPC, *Thornton Health*, UK: 283-292.

Honervogt, B. & Lehmann-Danzinger, H. (1992). Comparison of thermal and chemical treatment of cotton seed to control bacterial blight (*Xanthomonas campestris* pv. *malvacearum*). *Journal of Phytopathology*, 134: 103-109.

ISTA. (1996). International rules for seed testing. *Seed Science and Technology*. 24.

Lang, A. (1965). Effects of some internal and external conditions on seed germination. *Encyclopedia of Plant Physiology*, 15 (2): 848–893.

McDonald, M. B. (1999). Seed deterioration: physiology, repair and assessment. *Seed Science and Technology*, 27: 177–237.

Orlicz-Luthardt, A. (1998). On the transfer of *Fusarium* wilt by seeds in China aster. *Seed Science and Technology*, 26: 67-76.

Zhang, Z. (1997). Effect of plant growth regulator and osmopriming on seed germination and seedling emergence of chosen flower species. *M.Sc. dissertation*. Poznań Agricultural University.

Table 1. The effect of microwave seed treatment on the total number of germinating seeds (Gmax) and seed germination capacity

Seed treatment		Gmax (%)	Germination capacity (%)	
			I count	II count
Control I*		89.0 f**	64.7 gh	70.3 gh
Control II		75.0 de	54.7 cdef	61.3 efg
Dry microwave seed treatment	10 s	82.3 def	63.0 fgh	67.0 fgh
	20 s	84.3 ef	64.0 fgh	68.7 gh
	30 s	57.7 c	63.3 fgh	66.7 fgh
	40 s	49.3 c	45.7 c	47.3 c
	50 s	56.0 c	47.0 c	50.3 cd
	60 s	39.0 b	11.7 b	12.3 b
	90 s	55.3 c	61.0 efgh	63.7 efgh
	120 s	0 a	8.3 b	12.3 b
	180 s	0 a	0 a	0 a
Microwave seed treatment in water	10 s	81.0 def	53.0 cd	57.7 def
	20 s	81.0 def	58.0 efg	65.0 efgh
	30 s	77.3 de	61.0 efgh	70.0 gh
	40 s	80.7 def	57.7 defg	62.7 efg
	50 s	81.7 def	69.0 h	72.3 h
	60 s	76.3 de	66.3 gh	69.3 gh
	90 s	73.7 d	48.7 cd	56.7 de
	120 s	28.7 b	11.0 b	15.3 b
	180 s	0 a	0 a	0 a

* Control I – untreated seeds; Control II – seeds treated with Kaptan Zawiesinowy 50WP; dry microwave seed treatment for 10, 20, 30, 40, 50, 60, 90, 120 and 180 s respectively; microwave seed treatment in water for 10, 20, 30, 40, 50, 60, 90, 120 and 180 s respectively;

** Mean in columns follow by the same letters are not significantly different at α=0.05 level according to Duncan's multiple range test

Table 2. The effect of microwave seed treatment on the number of abnormal seedlings, dead seeds and fresh ungerminated seeds

Seed treatment		Abnormal seedlings (%)	Dead seeds (%)	Fresh ungerminated seeds (%)
Control I*		5.3 b	21.7 cd	2.7 ab
Control II		6.7 b	10.3 a	21.7 g
Dry microwave seed treatment	10 s	5.0 b	25.3 d	2.7 ab
	20 s	5.3 b	20.0 bcd	6.0 cd
	30 s	5.0 b	25.3 d	1.7 a
	40 s	9.3 bc	39.0 f	4.3 abcd
	50 s	9.0 bc	38.0 ef	2.7 abcd
	60 s	7.3 bc	74.8 h	6.0 cde
	90 s	5.3 b	27.7 de	3.3 abcd
	120 s	19.3 d	62.7 g	5.7 cde
	180 s	0.7 a	87.0 i	12.3 ef
Microwave seed treatment in water	10 s	7.3 bc	28.0 de	7.0 de
	20 s	10.0 bc	20.0 cd	5.0 bcde
	30 s	12.7 cd	11.7 ab	5.7 cde
	40 s	10.3 bc	21.3 cd	5.0 bcde
	50 s	9.0 bc	16.7 abcd	5.3 cde
	60 s	9.3 bc	14.0 abc	7.3 def
	90 s	9.8 bc	18.0 abcd	14.0 f
	120 s	6.0 b	20.7 cd	58.0 h
	180 s	0.3 a	43.3 f	54.7 h

* For explanation see Table. 1

Table 3. The effect of microwave seed treatment on the seed vigour – time to 1, 10 and 25% of the maximum germination (days)

Seed treatment		T_1*	T_{10}	T_{25}
Control I**		1.37 ab	1.70 a	1.95 abcd
Control II		1.36 ab	1.79 a	2.16 d
Dry microwave seed treatment	10 s	1.26 ab	1.51 a	1.70 a
	20 s	1.26 ab	1.54 a	1.77 ab
	30 s	1.16 ab	1.66 a	2.07 abcd
	40 s	1.61 b	1.84 a	2.28 d
	50 s	1.30 ab	1.63 a	1.91 abc
	60 s	1.24 ab	1.74 a	2.28 d
	90 s	1.09 a	1.71 a	2.03 abcd
	120 s	-***	-	-
	180 s	-	-	-
Microwave seed treatment in water	10 s	1.19 ab	1.60 a	1.87 abc
	20 s	1.50 ab	1.76 a	1.96 abcd
	30 s	1.17 ab	1.61 a	1.95 abcd
	40 s	1.16 ab	1.55 a	1.79 ab
	50 s	1.28 ab	1.51 a	1.77 ab
	60 s	1.47 ab	1.61 a	1.92 abc
	90 s	1.32 ab	1.58 a	1.80 ab
	120 s	1.43 ab	2.41 b	3.26 e
	180 s	-	-	-

* T1 – time to 1% of maximum germination, T10 – time to 10% of maximum germination, T25 – time to 25% of maximum germination

** For further explanation see Table 1

*** Seeds did not germinate

Table 4. The effect of microwave seed treatment on the seed vigour – time to 50, 75 and 90% of the maximum germination (days)

Seed treatment		T_{50}*		T_{75}		T_{90}	
Control I**		2.34	abcd	3.14	a	4.63	ab
Control II		2.87	e	4.41	d	6.85	ef
Dry microwave seed treatment	10 s	2.03	a	2.82	a	4.24	a
	20 s	2.13	a	2.92	a	4.51	ab
	30 s	2.50	abcd	4.11	bcd	6.16	def
	40 s	2.78	bcde	4.28	cd	7.03	f
	50 s	2.40	abcd	3.60	abc	5.71	bcde
	60 s	3.05	e	4.25	cd	6.23	def
	90 s	2.78	cde	4.08	bcd	5.97	cdef
	120 s	-***		-		-	
	180 s	-		-		-	
Microwave seed treatment in water	10 s	2.33	abcd	3.20	a	4.94	abc
	20 s	2.29	abcd	3.20	a	4.87	abc
	30 s	2.47	abcd	3.44	ab	5.06	abcd
	40 s	2.25	abc	3.19	a	4.91	abc
	50 s	2.15	a	3.14	a	4.72	abc
	60 s	2.30	abc	3.53	abc	5.67	bcde
	90 s	2.20	ab	3.25	a	5.26	abcd
	120 s	4.54	f	6.04	e	9.53	g
	180 s	-		-		-	

* T_{50} – time to 50% of maximum germination, T_{75} – time to 75% of maximum germination, T_{90} – time to 90% of maximum germination

** For further explanation see Table 1

*** Seeds did not germinate

Table 5. The effect of microwave seed treatment on the mean germination time and uniformity of germination (days)

Seed treatment		MGT*		Uniformity of germination			
				U_{75-25}		U_{90-10}	
Control I**		2.84	ab	1.19	ab	2.94	ab
Control II		3.75	e	2.32	cd	5.06	f
Dry microwave seed treatment	10 s	2.54	a	1.11	a	2.73	a
	20 s	2.66	ab	1.15	a	2.96	ab
	30 s	3.45	cde	2.05	a	4.39	cdef
	40 s	3.65	e	2.24	d	5.19	f
	50 s	3.16	bcd	1.69	abcd	4.08	bcdef
	60 s	3.52	de	1.97	cd	4.18	bcdef
	90 s	3.49	de	1.96	cd	4.52	def
	120 s	-***		-		-	
	180 s	-		-		-	
Microwave seed treatment in wate	10 s	2.82	ab	1.33	abc	3.15	abc
	20 s	2.89	ab	1.17	a	3.11	ab
	30 s	3.00	abc	1.49	abc	3.46	abcd
	40 s	2.83	ab	1.41	abc	3.42	abcd
	50 s	2.82	ab	1.42	abc	3.39	abcd
	60 s	3.12	bcd	1.61	abc	3.96	abcde
	90 s	2.91	ab	1.45	abc	3.68	abcd
	120 s	5.39	f	3.37	e	7.12	g
	180 s	-		-		-	

* MGT – mean germination time, U75-25 – time between 25% and 75% of maximum germination; U90-10 – time between 10% and 90% of maximum germination

**For further explanation see Table 1

*** Seeds did not germinate

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Table 6. The effects of microwave seed treatment on their infestation with Alternaria alternata, Cladosporium spp. and Penicillium spp.

Seed treatment		**Seed infestation with (%)**		
		Alternaria alternata	***Cladosporium* spp.**	***Penicillium* spp.**
Control I*		39.0 efg	2.5 cd	3.5 abcde
Control II		9.5 b	0.5 ab	0.5 a
Dry microwave seed treatment	10 s	47.0 g	1.5 abcd	1.5 abc
	20 s	42.0 fg	0 a	2.0 ab
	30 s	40.5 fg	0.5 ab	1.0 a
	40 s	28.5 cde	0 a	5.0 cdefg
	50 s	40.0 fg	1.0 abc	11.5 fg
	60 s	32.5 def	1.0 abc	7.5 efg
	90 s	35.0 ef	3.5 d	6.5 defg
	120 s	19.5 c	2.0 abcd	6.5 defg
	180 s	4.5 b	0 a	5.0 bcdef
Microwave seed treatment in water	10 s	36.5 efg	1.5 abcd	13.0 g
	20 s	35.5 efg	0 a	7.0 efg
	30 s	37.5 efg	2.0 bcd	6.0 defg
	40 s	37.5 efg	0.5 ab	3.0 abcde
	50 s	34.0 ef	0 a	5.0 defg
	60 s	22.5 cd	2.0 bcd	3.5 abcde
	90 s	26.5 cd	1.0 a	3.5 abcde
	120 s	0 a	0 a	0.5 a
	180 s	0 a	2.0 bcd	2.0 abcd

* For explanation see Table 1

Table 7. The effects of microwave seed treatment on their infestation with Epicoccum purpurascens, Mucor sp. and Rhizopus nigricans.

Seed treatment		Seed infestation with (%)		
		Epicoccum purpurascens	Mucor sp.	Rhizopus nigricans
Control I		2.0 a	1.0 ab	1.0 a
Control II		0 a	1.0 ab	0 a
Dry microwave seed treatment	10 s	1.5 a	0 a	0 a
	20 s	0 a	0 a	0.5 ab
	30 s	0.5 a	0.5 ab	0 a
	40 s	0.5 a	0 a	0 a
	50 s	1.5 a	0 a	0 a
	60 s	1.5 a	0.5 ab	3.0 bc
	90 s	1.0 a	0 a	0 a
	120 s	1.5 a	1.0 ab	0 a
	180 s	0.5 a	2.0 b	1.0 abc
Microwave seed treatment in water	10 s	1.0 a	1.5 b	0.5 ab
	20 s	0 a	0 a	0 a
	30 s	1.0 a	0 a	0.5 ab
	40 s	0.5 a	0 a	1.0 ab
	50 s	0 a	0 a	0 a
	60 s	0 a	0 a	0 a
	90 s	0 a	1.0 a	0 a
	120 s	0 a	0 a	0 a
	180 s	0 a	0 a	2.0 abc

* For explanation see Table 1

Table 8. The effects of microwave seed treatment on their infestation with Curvularia sp., Ulocladium spp. and the number of seeds free from fungi

Seed treatment		Seed infestation with (%)				Seeds free from fungi (%)	
		Curvularia sp.		Ulocladium spp.			
Control I		0	a	0	a	53.5	abc
Control II		0	a	0	a	89.5	f
Dry microwave seed treatment	10 s	0.5	a	5.0	d	46.5	ab
	20 s	0	a	3.5	cd	51.0	ab
	30 s	0.5	a	2.0	bc	55.5	abc
	40 s	0.5	a	0	a	66.0	cde
	50 s	0.5	a	1.5	bc	46.0	a
	60 s	2.0	b	1.0	abc	53.5	abc
	90 s	1.0	ab	1.0	abc	51.5	ab
	120 s	0.5	a	0	a	71.0	de
	180 s	0.5	a	0.5	ab	88.0	f
Microwave seed treatment in water	10 s	0.5	a	0	a	50.5	ab
	20 s	0.5	a	0	a	57.0	abc
	30 s	0	a	0	a	53.0	abc
	40 s	0	a	0.5	ab	56.0	abc
	50 s	0.5	a	0.5	ab	60.0	bcd
	60 s	0	a	0	a	73.0	cde
	90 s	0	a	1.0	abc	68.0	e
	120 s	0	a	0	a	99.0	g
	180 s	0	a	0.5	ab	91.5	f

* For explanation see Table 1

Table 9. Moisture content of untreated seeds and seeds treated with dry microwave

Seed treatment		Moisture content (%)
Control I		6.60
Dry microwave seed treatment	10 s	6.48
	20 s	6.35
	30 s	6.22
	40 s	6.10
	50 s	5.72
	60 s	5.30
	90 s	5.05
	120 s	4.85
	180 s	4.70

* Control I – untreated seeds; dry microwave seed treatment for 10, 20, 30, 40, 50, 60, 90, 120 and 180 s respectively

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