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Electrical Conductivity Relates Seed Germination and Seedling Emergence in Tagetes Seed Lots

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ABSTRACT

In this study, we tested whether electrical conductivity of solute leakage was related to seed germination, mean germination time, 24th hour seed germination, seedling emergence percentage, mean emergence time and seedling dry weight in nine different tagetes seed lots. Normal seed germination percentages of seed lots ranged between 55 and 96 %, and electrical conductivity values were between 151 and 770 µScm^{-1}g^{-1}. Seedling emergence ranged between 68 and 95 %, mean emergence time was 3.9 to 5.1 days, and seedling dry weight 3.1-8.1 g/plant. Electrical conductivity was significantly related to normal germination (R^2=0.64, $p<0.01$), 24 h radicle emergence (R^2=0.90, $p<0.001$), mean germination time (R^2=0.92, $p<0.001$), seedling emergence percentage (R^2=0.86, $p<0.001$), mean emergence time (R^2=0.87, $p<0.001$) and seedling dry weight (R^2=0.67, $p<0.05$). Results indicated that electrical conductivity is a potential seed quality test for tagetes seeds.

Keywords: Flower seeds, electrical conductivity, marigold, seed quality

Kadife Çiçeği Tohumlarında Elektriksel İletkenliğin Tohum Çimlenmesi ve Fide Çıkışı ile İlişkisi

ÖZ

Bu çalışmada elektriksel iletkenlik testinin kadife çiçeği tohumlarında toplam, normal tohum çimlenmesi, ortalama çimlenme zamanı, 24 saat kökçük çıkışı fide çıkış oranı fide çıkış zamanı ve fide yaş ağırlığı ile ilişkilendirebileceği araştırılmıştır. Toplam çimlenme %96'dan yüksek, normal çimlenme %55 ve 96 arasında, Eİ değerleri 151 ve 770 µScm^{-1}g^{-1} arasında oluşmuştur. Fide çıkış oranı %68 ve 95 arasında, ortalama çıkış zamanı ise 3.9 ile 5.1 gün arasında, fide kuru ağırlığı da 3.1 ile 8.1 g/bitki arasında değişmiştir. Elektriksel iletkenlik toplam çimlenme (R^2=0.89, $p<0.001$), normal çimlenme (R^2=0.64, $p<0.01$), 24 saat kökçük çıkışı (R^2=0.90, $p<0.001$), ortalama çimlenme zamanı (R^2=0.92, $p<0.001$) değerleri ile anlamlı bir ilişki göstermiştir. Fide çıkış oranı (R^2=0.86, $p<0.001$), ortalama çıkış zamanı (R^2=0.87, $p<0.001$), fide kuru ağırlığı (R^2=0.67, $p<0.05$) ile de Eİ değerlerinin istatistiksel olarak anlamlı şekilde ilişkili olduğu saptanmıştır.

Anahtar Kelimeler: Çiçek tohumları, elektriksel iletkenlik, kadife çiçeği, tohum kalitesi

INTRODUCTION

Standard laboratory germination tests are carried out at optimum germination conditions but take several days to complete. Shorter time frames for determination of normal seedling percentages of any seed lot can be practical for seed producers aiming to make quick decisions concerning seed sales, storage, use of it. Electrical conductivity (EC) is one potential quick test that measures the leakage of electrolytes from seeds into soak water [1, 2]. Seed quality loss, i.e. lower germination, is associated with cell membrane deterioration due to ageing, which accelerates solute leakage. Non-germinable or low germination seed lots therefore leak high levels of solutes into soak water. So, the older and the more aged the seed, the greater the leakage.

The use of EC measurements of seeds has been used successfully to predict germination in vegetable seeds [3, 4, 5, 6]. However, there is lack of research in testing EC as a seed germination indicator in flower seeds [2]. Tagetes spp. are widely used in Turkey. They are widely planted particularly in summertime. A minimum legal standard germination percentage is not necessary in flower seeds for sale. In contrast to the situation for crop species, there are no minimum

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levels of germination percentages below which seeds of wild species cannot be sold. It would be more important to use an EC test to predict germination percentages of the flower seed lots. The seed lots with higher values of germination are likely to produce strong transplants in modules or in the field [7] in marigold and native wild flower seeds [2]. However, there is a lack of methods and routine protocols for assessing seed quality in flower seed species [8]. Laboratory germination testing is definitely the most common approach for seed quality evaluation in flower species as it provides information on a range of cues (e.g. temperature and light conditions) that, in most cases combination, may be needed, particularly if dormancy is present, for successful germination and emergence of seedlings under field conditions [9]. The broad range of germination responses exhibited across native species and the long periods of time necessary to achieve germination [10] suggest the need for the development of effective and quicker alternatives. Being able to predict the legal germination percentages of any lot by a quick test would help flower seed producers make a fast-marketing decision.

The objective of the present study was to examine whether the EC of the soak water of seed bulks related to standard germination, seedling emergence, mean germination and emergence time and seedling dry weight in marigold seed lots.

MATERIALS AND METHODS

Nine different seed lots of marigold (*Tagetes erecta*) (Table 1) were obtained from commercial seed companies. For the germination test, four replicates of 25 seeds were placed on filter paper (Filtrak, Germany) in a petri dish (9 cm) wetted with 0.2% KNO_3 instead of distilled water and subsequently placed at 5°C for seven days for pre-chilling in the dark. Then, the dishes were placed in polyethylene bags to prevent evaporation and placed in an incubator at 20°C. Total germination percentages (2 mm radicle emergence) were counted daily starting with 24h (radicle germination) until 21 days at this temperature (pre-chilling stage, 7 days + germination stage, 21 days = 28 days). Normal (well-developed seedling parts) were also counted after 21 days.

The mean germination/emergence time (MGT/MET) was calculated using the formula;

MGT / MET = Σ n. t / Σn

where n = number of seeds newly germinated / emerged at time t; t = days from planting; and Σn = final germination/emergence

Seedling Emergence Test

Four replicates of 25 seeds of each lot were sown randomly 1 cm deep in peat moss (Plantaflor-Humus, Verkaufs-GmBH, Germany) in seedling trays (320×200×60 mm) and placed in the incubator at 23±2°C. Light was provided by cool fluorescent lamps (72 μMm^{-1}second-1) for about 12 hours a day. The relative humidity in the cabinet was controlled and kept over 65-75% to reduce evaporation. Normally developed seedlings (fully developed cotyledons, without any necrotic area and missing upper organs) were counted after 20 days. A count was made daily and the appearance of the cotyledons at the surface was used as an emergence criterion. MET was calculated as described above. Twenty seedlings were selected randomly and the dry weight was determined after drying at 80°C for 24 hours. Mean seedling dry weight was expressed as g/plant in each lot.

EC Measurement

Three replicates of 25 seeds were weighed and soaked in 40 ml of distilled water at 20°C in the dark. EC was measured after 24 hours. The conductivity of seed soak water was measured using a conductivity meter (Schott-Gerate GmbH, Hofheim) and expressed per gram of seeds ($\mu Scm^{-1}g^{-1}$). The mean of the three samples was taken for each lot.

Statistical Analysis

Comparison of means in the lots were made at the 5% level. Correlations in marigold seed lots between EC values and total, normal percentages, 24th hour radicle emergence, mean germination and emergence time, seedling emergence and dry weight were calculated. Statistical analysis was performed using SPSS to carry out ANOVA and logit regression analysis. Regression values were used to test significance at levels of 0.05-0.001.

RESULTS

Total germination percentages of tagetes seed lots ranged between 96% and 100%, normal germination was between 55% and 96%, 24th day radicle emergence between 63% and 100%, and mean germination time 1-1.8 days. Electrical conductivity values were the highest in lot 9 at 770.7 and the lowest in lot 2 at 151.3 $\mu Scm^{-1}g^{-1}$. Lots 8 and 9 had the lowest values in general compared to the other seven seed lots. MGT values of the first six lots had one day which means that more than 98% germinated in a day. Lots 7, 8 and 9 germinated slightly later as 1.1, 1.5 and 1.8 days respectively (Table 1).

The difference between total and normal germination was just 4-9%, while starting with lots 5 to 9, normal germination percentage gradually fell to 55%. Seedling emergence ranged between 68 and 95%, mean emergence time was between 3.9 and 5.1 days, and seedling dry weight was between 3.1 and 8.1 mg/ plant (Table 2).

Correlation values are presented in Table 3. Results indicated that all seed germination and seedling quality characters were related to EC at a very high level (r=0.803-0.958, P<0.01-0.001).

Table 1. Total, normal germination percentages, 24h germination (%), mean germination time (days) and electrical conductivity ($\mu Scm^{-1}g^{-1}$) values of nine different marigold (*Tagetes erecta*) seed lots

Seed Lots	TG (%)	NG (%)	24^{th} G (%)	MGT (day)	EC ($\mu Scm^{-1}g^{-1}$)
1	100 a	96 a	98 a	1 a	267 a
2	100 a	93 a	100 a	1 a	151 a
3	99 a	93 a	99 a	1 a	265 b
4	100 a	91 a	100 a	1 a	221 a
5	100 a	86 ab	99 a	1 a	176 a
6	100 a	74 c	100 a	1 a	220 a
7	100 a	72 c	89 b	1.1 a	205 a
8	98 a	58 d	66 c	1.5 a	723 b
9	96 a	55 d	63 c	1.8 a	770 c
Range	96-100	55-96	63-100	1-1.8	151-770

[TG (Total germination), NG (Normal germination, MGT (Mean germination time), EC (Electrical conductivity)]; Values with different letters are significant at the 5% level in the same column.

Table 2. Seedling emergence percentages and mean germination time (days) and seedling dry weight (mg/plant) values of nine marigold (*Tagetes erecta*) seed lots

Seed Lots	Seedling emergence (%)	Mean emergence time (day)	Seedling dry weight (mg/plant)
1	89 a	3.9 a	5.4 d
2	96 a	4.0 a	6.2 bd
3	95 a	4.2 ab	5.5 c
4	89 a	3.9 a	8.1 a
5	86 a	4.0 a	6.1 bd
6	88 a	4.2 ab	6.5 bc
7	88 a	3.7 a	6.6 b
8	68 b	4.8 bc	3.1 e
9	70 b	5.1 c	4.0 e
Range	68-95	3.9-5.1	3.1-8.1

Values with different letters are significant at the 5% level in the same column.

The significance level with EC with normal germination and seedling dry weight was 0.01 and the rest were 0.001 (Table 3). The highest correlation (r) was seen in EC and 24^{th} radicle germination and mean germination time as 0.951 and 0.958. Regression figures indicated that electrical conductivity was highly related to both seed germination and seedling quality factors. The R^2 values ranged between 0.645 and 0.918 (p=0.05-0.001) (Figure 1).

Table 3. Correlation coefficients and significance relationship between germination and emergence tests and the electrical conductivity test

Quality Tests	Electrical Conductivity
Total germination	0.9460***
Normal germination	0.803**
24^{th} germination	0.951***
Mean germination time	0.958***
Seedling emergence	0.928***
Mean emergence time	0.933***
Seedling dry weight	0.840**

**p<0.01, ***p<0.001

DISCUSSION

The high correlation between EC measurements, total and normal seed germination and seedling parameters indicates that conductivity readings have the potential to provide a rapid assessment of seed quality in tagetes seeds (Table 3, Figure 1). Information about the germination percentages of any lot can be obtained within the very short time of 24 hours, compared to the 14 days' germination test for marigold.

The relation between solute leakage and germination percentages was high (p<0.001) in both total and normal germination conducted in laboratory conditions. The results show that conductivity indicates not only the germination differences in total germination (2 mm radicle emergence) but also normally developed seedling germination percentages. This obviously indicates that dead or abnormal seedlings in the population contribute most to the overall leakage (Figure 1).

It was reported [11] that mean conductivities of single oilseed rape seeds after 24 h of soaking were 4.9, 6.9 and 15.1 $\mu Scm^{-1}g^{-1}$ respectively in normal, abnormal and dead seeds. In our work, the highest number of abnormal seedling percentages, 40 and 41% in lots 8 and 9, had the highest EC values of 723.4 and 770 $\mu Scm^{-1}g^{-1}$ respectively among all lots. The other seven seed lots had a normal germination of 72 and 96%, and leakage of much lower values of 151 and 267 $\mu Scm^{-1}g^{-1}$. This result tallies with the conclusion in cabbage and cauliflower [3], radish [12] and wild flower seeds [2]. We measured the leakage of bulk seed samples measuring the overall mean of all seed leakage (dead, abnormal together, etc.) Our results indicate that higher solute leakage would occur in lots with a high proportion of dead or abnormal seeds.

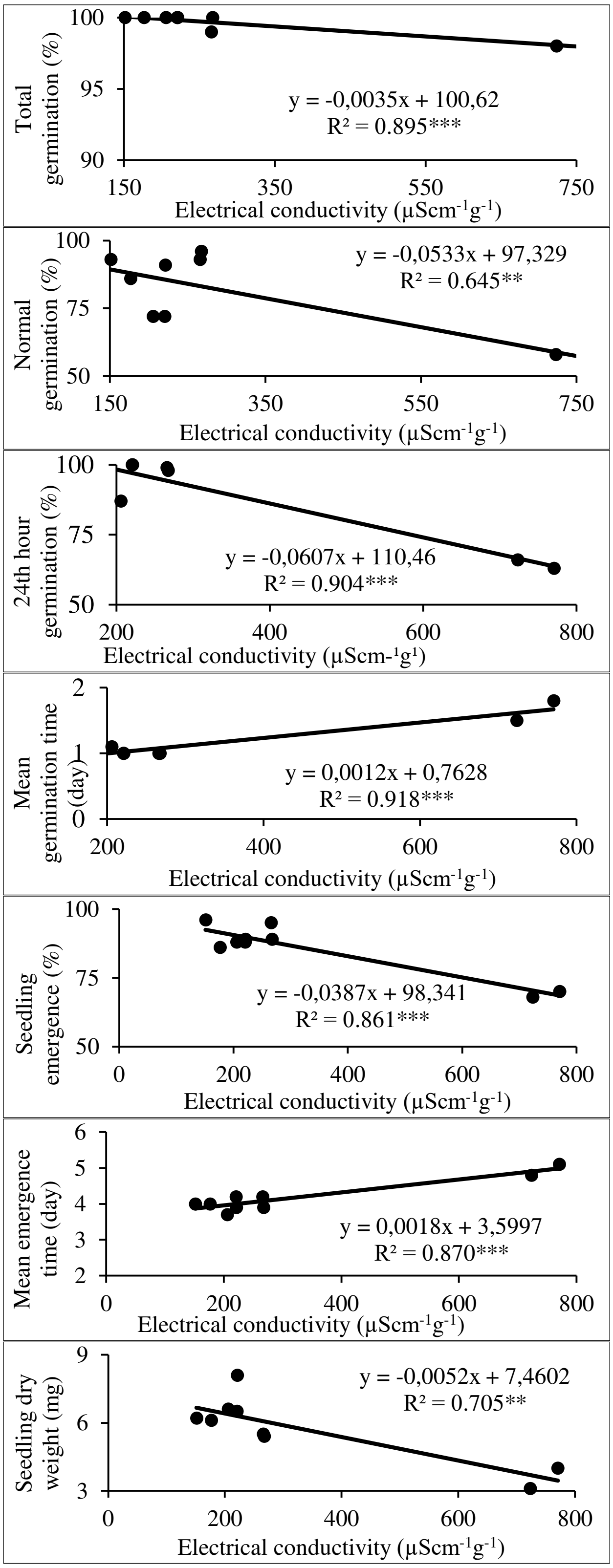

Figure 1. Regression curves and significance levels between electrical conductivity and germination percentage (normal and total), mean germination time, 24th hour germination, seedling emergence, seedling dry weight and mean emergence time in marigold seed lots

The close relationship between germination and bulk conductivity in artificially aged cabbage and cauliflower [3] and naturally aged cabbage seed lots [13] and radish seeds [14] indicates that the average conductivity reading per gram seed weight in the bulk conductivity method is successful.

Various physiological events are associated with seed ageing. One of these is the loss of cell membrane integrity. Cell membranes lose their semi-permeable structure and increase solute leakage [15, 6, 17]. In this study we used seed lots at different seed germination percentages to test the relationship between EC and germination percentages. These lots were collected from the seed market and they were assumed to be naturally aged on market shelves. Some of the earlier studies that try to discriminate seed lots by EC test were produced through artificial ageing at high temperature and relative humidity [3, 13]. In that sense the question arises whether ageing type effects the EC and seed quality relationship. It was noted [18] that the physiological effects of ageing increased solute leakage regardless of ageing type (natural or artificial). Logit regression equations showed a high relationship in EC values and seedling quality features in marigold seeds (Figure 1). These results were in agreement with earlier findings in some vegetable crops [14, 17] that EC is an indicator of seed vigour which is reflected in higher seedling emergence in modules or field sowings where some non-optimum environmental conditions can prevail during emergence. This finding indicates that EC can have a potential to test seed vigour in marigold seeds. The definition of vigour by the ISTA is “Seed vigour is a sum of those properties that determine the activity and level of performance of seed lots of acceptable germination in a wide range of environments”. The seed vigour characteristics of a seed lot in flower seeds are associated with the uniformity of seed germination and seedling growth and the emergence ability of seeds under unfavorable environmental conditions, i.e. emergence in modules and fields [19]. The electrical conductivity test for legumes such as peas was validated by ISTA [20], and it can be used to discriminate between seed lots regarding seedling emergence in modules or in the field.

CONCLUSION

In conclusion, this study presents the possibility of detection germination percentages through EC in samples with various germination levels in marigold seed lots. EC can be used to check germination percentages of leftover seeds (seeds produced the previous year but not sold) before marketing. The detection appears to be achievable by predictive regression equations between EC and germination, but further work with larger seed lots can be beneficial in order to get more concrete conclusions.

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