Predicting seedling emergence of cabbage and onion using vigour tests

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Predicting seedling emergence using standard and non-standard germination temperatures, standard accelerated ageing (AA) and saturated salt accelerated ageing (SSAA) tests, were investigated. Germinations were performed at temperatures of 10°, 20°, 20°/30° and 30°C for cabbage (*Brassica oleracea* var. *capitata* L.) and 10°, 15°, 20° and 30°C for onion (*Allium cepa* L.). Seeds were aged using relative humidities of 32% (RH32), 43% (RH43), 75% (RH75) and 100% (RH100). Emergence trials were conducted at a range of temperatures (winter, 15°/25° and 30°C) and growth media. Most SSAA vigour tests were useful in differentiating seed lots based on their physiological stage of deterioration. In the SSAA tests, the seed moisture content remained below 14% and no fungal growth occurred. For cabbage, highly significant correlations were obtained between 10°C and RH32 and all emergence trials. For onions highly significant correlations with emergence percentage were obtained with germinations at 15° and 30°C. Mean germination time (MGT) and germination energy (GE) were valuable in categorising seed lots with moderate vigour levels, however, only GE revealed good correlation with winter emergence trial of onions.

Key words: Cabbage, emergence, germination, onion, saturated accelerated ageing test

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Introduction

Although germination is a complex process, it has only three requirements: water, favourable temperature and oxygen. Seeds are sown into soil at varying temperatures and moisture contents (Benjamin, 1990). This can result in non-uniform, late and low emergence percentages. Consequently, growers started to use transplants by raising seedlings in containers where they can control temperature and amount of water. The amount of water can easily be managed at low cost. However, to control temperature a larger amount of initial and running capital is required. For these reasons, temperature has been taken as the limiting factor in seedling production. Vegetable crops such as cabbage and onion are planted either directly or using transplants. In both cases, high vigour seeds that can withstand a wide range of environmental variations are important in obtaining synchronised germination and uniform seedlings at the recommended plant population.

Germination testing is used to estimate the maximum number of seeds that will produce normal seedlings, while giving repeatable results (ISTA, 1999). These results can be used to compare the quality of different seed lots and also estimate the field planting value (Benjamin, 1990). When field conditions are near optimum, the standard germination test may accurately predict seedling emergence in the field. Seeds can germinate at a wide range of temperatures, but the germination percentage is drastically reduced at extreme temperatures (Copeland & McDonald, 2001). The range of temperatures at which the maximum germination percentage occurs, differs among crops and with seed quality. In general, temperature range becomes narrower as a seed lot deteriorates (Ellis & Roberts, 1981). Germination of seeds under non-standard temperatures can thus be used as a vigour test for differentiating low and high vigour seed lots, where low vigour seeds have a narrower temperature range than high vigour seed lots.

When environmental conditions are not favourable, additional tests, like seed vigour, are required to provide reliable information on potential crop establishment (Tekrony, 2003). The accelerated ageing (AA) test is one of the most widely accepted vigour tests to predict the emergence of large seeded agronomic crops (McDonald, 1998). However, it had some limitations when it was used for small seeded vegetables due to rapid absorption of water by the small seeds during ageing. As a result of these limitations, the standard AA test was modified by using saturated salt solutions instead of water (Jianhua & McDonald, 1996). Since relative humidity of saturated salt solutions is lower than that of water (100%), smaller seeds may absorb water more slowly. As the relative humidity of the accelerated ageing chamber declines, seed moisture content decreases. Due to the use of saturated salts, this method is referred to as the saturated salt accelerated ageing (SSAA) test. The SSAA was used in distinguishing vigour differences between seed lots of impatiens (*Impatiens wallerana*) (Jianhua & McDonald, 1996). The SSAA could also be helpful in predicting field emergence of small seeded vegetables.

The aims of these trials were: (1) to evaluate the ability of non-standard temperatures test results in predicting the seedling emergence of cabbage and onion planted under a wide range of temperatures; (2) to evaluate the predictive value of the SSAA vigour test for seedling emergence of cabbage and onion.

Material and methods

Six seed lots of cabbage cultivar 'Copenhagen Market' (A to F) and seven seed lots of onion cultivar 'Red Creole' (A to G) were obtained from Hygrotech Seed Company. The seed lots are commercially acceptable, with a range of germination 84 to 95%, as determined by the seed company. All the seed lots were stored in sealed containers in a cold room at 6°C. The required quantity of seeds was taken from the store just prior to the start of an experiment.

Laboratory tests

Germination: Seeds were incubated at various standard temperatures according to the rules of the International Seed Testing Association (ISTA, 1999). The standard temperatures were 20° and 20°/30°C for cabbage and 15° and 20°C for onion. Together with the standard germination temperatures, two non-standard temperatures (10° and 30°C) were used for both crop seeds. Germination tests were performed using Labcon germination cabinets. Fifty seeds were placed in 90 mm Petri dishes layered with double filter paper (Whatman no 1) moistened with 5 ml of distilled water, to which extra water was added when needed. The Petri dishes were arranged in a completely randomised design with four replications. Germination was defined as emerged normal seedling (ISTA, 1999). The final germination percentage (FGP) was calculated.

For measuring viability and germination rate parameters, seeds were incubated at 20°C. Germination was recorded daily over a period of 10 days for cabbage and 12 days for onion. A seed was regarded as germinated when its radicle had protruded. Seeds that did not germinate within the specified days were considered as non-viable. From the daily counts (visible radicle) germination capacity (GC) or viability, germination energy (GE) and mean germination time (MGT) were calculated as:

$$GC = \frac{\textit{number of seeds with visible radicle}}{\textit{total number of seeds used}} \text{ X } 100$$

$$GE = \frac{\textit{number of seeds with visible radicle at day 3 (cabbage) or 5 (onion)}}{\textit{total number of seeds used}} \text{ X } 100$$

$$MGT = \frac{\Sigma(nd)}{\Sigma n}$$

Where n = number of seeds germinated on day (d);
d = number of the day
Σn = total number of germinated seeds

AA and SSAA: The standard AA and SSAA tests were conducted according to the methodologies of Tekrony (1995) and McDonald (1997), respectively. Three saturated salt solutions and distilled water were used to create different relative humidities [distilled water (RH100: 100%), NaCl (RH75: 75%), Ca (NO3) 2 (RH43: 43%) and MgCl2 (RH32: 32%)]. The saturated solutions were prepared by dissolving the salts in distilled water until saturation. Ageing chambers consisting of outer and inner boxes were used. A Labcon incubator was used as the outer box, while the inner box was made up of a plastic container with sealable lid in which a screen tray was placed to prevent direct contact of seeds with the distilled water or saturated salt solution. Each inner ageing box received 40 ml of distilled water (for standard AA) or saturated salt solution (for SSAA). From each seed lot, 300 seeds (± 1 gram) were placed on the screen tray and spread out in a single layer. The seeds were left to age for 72 hours at a temperature of 41°C. After aging, the inner boxes were removed from the outer box. Seeds were then removed from the inner box. Moisture contents of the aged seeds were determined and a standard germination test (ISTA, 1999) was conducted.

To determine the moisture content, two replicates of fifty seeds from each seed lot were weighed immediately after removing them from the incubator. Seed moisture of each seed lot was determined after drying seeds at a temperature of 103°C for 18 hours (ISTA, 1999). For the germination test, four replicates of fifty seeds from each seed lot were used. Seeds were placed on two layers of filter paper (Whatman no 1) in 90 mm Petri dishes and incubated at 20^{o}C. The Petri dishes were arranged in a completely randomised design with four replications. Normal seedlings were recorded and the percentages were calculated according to ISTA (1999) rules.

Emergence tests

All the experiments were conducted in 2003 on the Hatfield Experimental Farm of the University of Pretoria (25^{o} 45\` S; 28$^{o}$ 16\` E; altitude 1372 m a.s.l). Three temperatures namely: high, favourable and low were used. One of the experiments was conducted in an open field in winter during the coldest months (June-July) of the year. Temperature data were obtained from a weather station at the experimental site. Minimum, mean and maximum temperatures were 5.01°, 11.93° and 19.06°C respectively. The remaining two trials were conducted in controlled environmental conditions of 15°/25°C night/day (favourable) and 30°C (hot). To investigate if a growth medium has an effect on emergence of seed lots, two media were used: a commercial medium "Hygromix" containing peat-lite and vermiculite (Hygrotech Seed Company) and a sand clay loam soil from the Experimental Farm.

In this experiment, 128 cavity seedling trays were used after they were sterilised with 10% Sodium Hypo-Chlorite. The trays' cavities were filled either with Hygromix or soil. Before use, the soil was sieved by using a 2 mm sieve. Fifty seeds per seed lot were used and one seed was sown per cavity at a depth of 1 to 1.5 cm. The trays were watered once a day during cool (winter) conditions and twice a day during favourable (15°/25°C) and hot (30°C) conditions. A factorially-designed experiment with two crops, 13 seed lots and two growing media was used. Four replicates of each treatment were allocated at random with separate blocks for each species. Emerged seedlings were counted until emergence ceased and final emergence percentage (FEP) was calculated.

Statistical analysis

Data were analysed using SAS (SAS, 1999) and LSD_{Tukey} was calculated at $\alpha = 0.05$. Correlation coefficients were determined between laboratory and emergence test results. The correlation analysis was based on mean values for each seed lot. The best vigour tests to predict emergence were identified using stepwise comparison at $\alpha = 0.01$ (Gomez & Gomez, 1984).

Results and discussion

Ageing conditions

Seeds of both crops had moisture contents ranging from 6 to 10% (fresh mass basis) before ageing. For all seed lots, the seed moisture content increased markedly as the RH increased (Table 1). In all conditions, the moisture content of cabbage seeds was lower as compared to onion seeds. The moisture difference may have originated from the chemical composition or fat content of the species. Copeland and McDonald (2001) also reported similar results for the *Brassica* group to which cabbage belongs.

For both crops, the standard AA test resulted in high variations (above 4%) in seed moisture contents (Table 1). According to Rodo and Marcos-Filho (2003), a variation of seed moisture content above 4% between seed lots is out of the acceptable range. Powell (1995) reported variation in seed moisture content ranging from 11.8 to 24.0% among onion seed lots, after 24 hours of accelerated ageing (100% relative humidity at 45ºC). Tekrony (1995) suggested seed moisture contents ranging from 39 to 44% for cabbage and 40 to 45% for onion to be acceptable. Results from the current study confirm this high variation in seed moisture content. Hence, it is not advisable to age small vegetable seeds, such as cabbage and onion, using the standard AA test (McDonald, 1997).

Table 1 Moisture content of seed lots of cabbage and onion before (control) and after aged at different relative humidities

	Moisture content (%)	
	Cabbage	Onion
Before ageing	6.5-8.3 (±1.8)*	8.2-9.8 (±1.6)
RH100	29.8-38.7(±8.9)	34.4-45.2 (±10.8)
RH75	8.1-10.7 (±2.6)	9.7-13.1 (±3.4)
RH43	7.4-8.8 (±1.4)	8.5-12.2 (±3.7)
RH32	5.3-6.7 (±0.8)	6.6-7.2 (± 0.8)

*standard deviation

Fungal growth was observed on the seeds in the standard AA test (RH100) (Fig. 1). This was encouraged by high moisture content of the seeds resulting from the high relative humidity. According to Kulik (1995) fungi can attack and destroy seeds over a wide range of relative humidities (65 to 100%) and temperature (4° to 45°C). Seeds with a moisture content of 18 to 30% rapidly deteriorates due to micro-organism activity. The moisture contents of the seeds of both crops after the SSAA (RH75, RH43 and RH32) were lower than 14% and no fungal growth was observed (Fig. 1). Similarly, no fungal growth was reported in impatiens seeds (Jianhua & McDonald, 1996) after seeds were aged with NaCl, KCl and NaBr solutions.

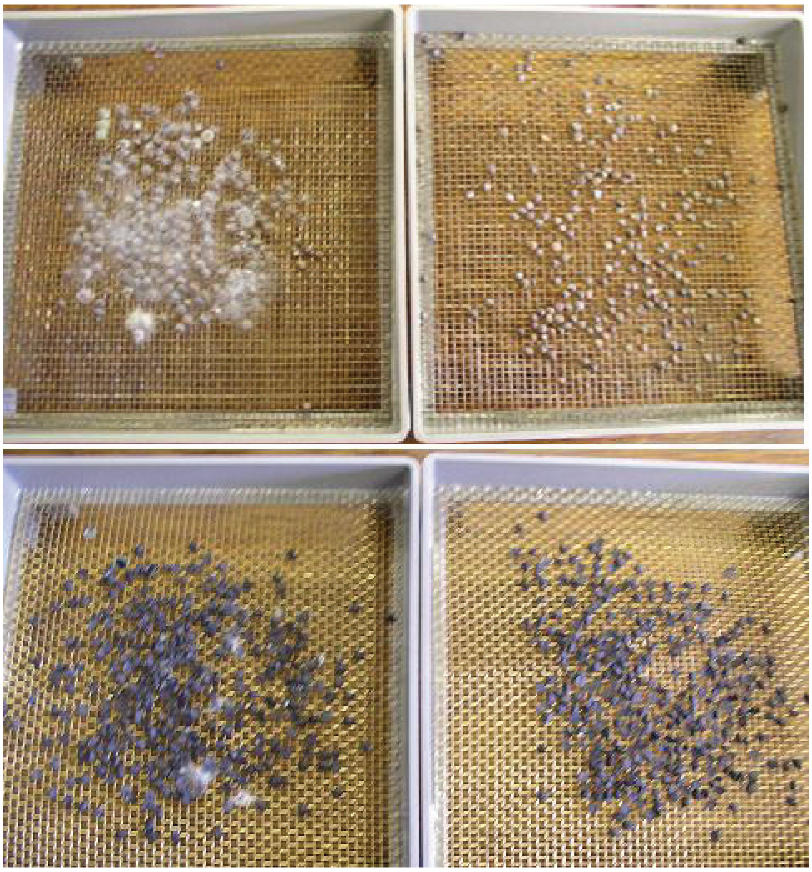

Figure 1 Fungal growth on cabbage and onion seeds subjected to the standard AA (RH100) and SSAA (RH75) tests.

Table 2 One way ANOVA and ranking of cabbage seed lots based on laboratory and emergence tests

	Normal germination percentage				Viability	Rate of germination		Normal germination percentage				Emergence percentage		
Seed lot	10°C	20°C^z	20°/30°C^z	30°C	GC	GE	MGT	RH100	RH75	RH43	RH32	Winter	15°/25°C	30°C
A	79.5a^y	90.5ab	89.5ab	90.0ab	93.0a	88.5ab	2.10b	29.0d	69.0c	74.0a	79.0a	58.8cd	84.3bc	80.0b
B	91.0a	92.5ab	91.0ab	92.0a	95.0a	93.5a	1.73a	61.0b	80.5ab	80.5a	83.0a	81.3ab	91.3ab	89.3a
C	56.0b	82.0b	78.0c	81.0b	86.0a	65.0c	3.11c	8.5f	42.0d	25.0b	65.5b	48.8d	75.0c	70.5c
D	82.0a	87.5ab	84.0bc	87.0ab	91.0a	79.0b	2.84c	49.0c	73.5bc	79.0a	84.5a	70.3bc	91.5ab	88.3ab
E	85.0a	89.0ab	90.5ab	91.5a	92.5a	91.5ab	1.88ab	19.0e	64.5c	76.0a	82.5a	77.8ab	90.8ab	88.8ab
F	96.0a	96.0a	94.5a	96.0a	97.0a	97.0a	1.72a	71.5a	87.5a	82.0a	85.0a	88.5a	96.3a	94.0a
Mean	81.66	89.50	87.92	89.58	92.33	85.75	2.23	39.67	69.5	69.42	79.92	70.88	88.17	85.13
CV (%)	12.35	6.14	4.59	4.96	5.74	7.15	5.60	11.17	6.29	6.03	5.12	9.54	5.93	4.61
F value	7.73*	2.82*	8.64*	5.32*	1.90^NS	14.96*	92.74*	126.22*	52.01*	110.18*	13.0*	19.30*	8.23*	18.64*
LSD_T	22.68	12.35	9.07	9.98	11.92	13.78	0.28	9.91	9.82	9.40	9.19	15.29	11.75	8.82
Range	40.0	14.0	16.5	15.0	11.0	32.0	1.41	63.0	45.5	57.0	19.5	39.75	21.25	18.5

^z Standard germination temperatures. ^y Values in each column followed by the same letters were not significantly different. GC: germination capacity (% final radicle protrusion), GE: germination energy (% radicle protrusion at the 5th day) and MGT: mean germination time. ^NS Not significant and * significant at 5%.

Table 3 One way ANOVA and ranking of onion seed lots based on laboratory and emergence tests

	Normal germination percentage				Viability	Rate of germination		Normal germination percentage				Emergence percentage		
Seed lots	10 °C	15°C^z	20°C^z	30°C	GC %	GE	MGT	RH100	RH75	RH43	RH32	Winter	15°/25°C	30°C
A	80.0ab^y	86.0bc	90.5abc	87.0ab	93.0abc	71b	4.29b	65.0b	77.0abc	69.0a	89.0ab	81.8ab	89.5ab	89.8ab
B	83.0a	92.5ab	94.5a	91.0a	96.5ab	91a	2.56c	81.0a	85.0a	82.0a	92.0a	86.5a	91.3a	90.0ab
C	81.0a	94.5a	93.5ab	89.0a	97.5a	82ab	3.04c	66.0b	82.5ab	71.5a	93.5a	86.8a	93.5a	91.0a
D	71.5bc	82.0c	84.5d	86.0ab	88.5c	52c	4.49b	42.0c	59.0d	45.0b	82.5cd	78.5abc	82.3bc	82.0bc
E	78.0ab	84.0c	86.0cd	82.5bc	89.5c	54c	4.24b	59.5b	65.5bcd	69.5a	85.5bc	72.5bc	82.0bc	73.8c
F	63.0c	81.0c	88.5bcd	77.5c	91.5bc	22d	6.63a	45.0c	61.5cd	33.0b	79.0d	67.8c	81.3c	73.8c
G	82.5a	87.0bc	91.5abc	89.0a	95.0ab	84ab	2.95c	80.0a	83.0ab	74.0a	89.5ab	83.8ab	86.3abc	86.5ab
Mean	77.0	86.71	89.85	86.0	93.14	65.14	4.03	62.64	73.36	63.43	87.29	79.64	86.50	83.82
CV (%)	5.21	3.47	2.68	2.37	2.55	9.98	11.16	9.29	10.41	8.99	2.96	3.07	4.08	4.53
F value	13.19*	11.56*	9.57*	15.25*	8.47*	55.9*	37.49*	27.61*	8.39*	38.08*	16.34*	70.91*	7.47*	15.61*
LSD_T	9.22	6.91	5.54	5.45	5.45	14.95	1.03	13.38	17.56	13.10	5.94	11.53	8.12	8.74
Range	20.0	13.5	10.0	13.5	9.0	69.0	4.06	39.0	26.0	49.0	14.5	19.0	12.25	17.25

^z Standard germination temperatures. ^y Values in each column followed by the same letters were not significantly different. GC: germination capacity (% final radicle protrusion), GE: germination energy (% radicle protrusion at the 3rd day) and MGT: mean germination time. * Significant at 5%.

For both crops, germination percentages for all ageing conditions were lower than that of the control, with the exception of the germination percentage after ageing at RH32. Powell (1995) found that low vigour seed lots absorbed moisture rapidly, reaching high moisture contents after only one day, and had a lower germination percentage as compared to high vigour seed lots that absorb water relatively slowly. The highest germination percentage was recorded at the control followed by RH32, RH75, RH43 and lowest at RH100. As shown in Tables 2 and 3 lower germination percentages were obtained after ageing seeds at RH43 as compared to RH75. This could be due to the fluctuation in relative humidity with minor fluctuations in temperature. Winiston and Bates (1960) reported a loss of some or all of the water due to dehydration as the temperature rose to ± 42°C when using $Ca(NO3)_2$.

Comparison of seed lots

There were significant differences between the seed lot means of cabbage for all laboratory and emergence test parameters except for GC (Table 2). While, significant differences were observed among the seed lot of onion of all germination and ageing test parameters (Table 3). Relatively small ranges of normal germination percentages occurred among germinations at 20°, 20°/30° and 30°C for cabbage, and at 15°, 20°, 30°C and RH32 for onion. Generally, based on the different germination and vigour test results cabbage seed lots can be categorised as high (B and F), medium (A, D and E) and low (C). Similarly, onion seeds can also be distinguished as high

Table 4 Correlation coefficients (r^2) between laboratory test and emergence test results of cabbage and onion seeds

	Emergence percentage					
	Cabbage (n = 6)			Onion (n = 7)		
	Winter	15°/25°C	30°C	Winter	15°/25°C	30°C
Germination %						
10°C	0.88*	0.92**	0.92**	0.70	0.52	0.53
15°C	-	-	-	0.72	0.88**	0.62
20°C	0.71	0.70	0.68	0.51	0.76*	0.56
20°/30°C	0.70	0.66	0.67	-	-	-
30°C	0.79	0.76	0.76	0.96**	0.61	0.81*
Viability test						
GC	0.76	0.76	0.74	0.57	0.78*	0.58
Germination rate						
GE	0.72	0.69	0.71	0.90**	0.67	0.74
MGT	0.61	0.49	0.52	0.64	0.38	0.48
Ageing tests						
RH100	0.62	0.66	0.63	0.53	0.46	0.42
RH75	0.74	0.85*	0.82*	0.72	0.76*	0.68
RH43	0.64	0.83*	0.81*	0.58	0.50	0.42
RH32	0.73	0.93**	0.91*	0.83*	0.85*	0.72

*Significant at α=0.05, **significant at α=0.01.

(B and C), moderate (A, E and G) and low vigour (D and F) seed lots. High vigour seed lots did not differ much in terms of germination capacity and germination percentage at various temperatures. The same was not true for the low vigour seed lots.

Ellis and Roberts (1980) suggested the use of germination rate as a second aspect of vigour in seed quality testing. The concept is that low vigour (deteriorated) seeds take longer to germinate as compared to high vigour seed lots. Coolbear (1995) confirmed that the slower germination from low vigour (partially deteriorated) seeds could be due to the additional time needed to undertake self repair. In agreement with this, low vigour seed lots of both crops had the longest MGT as compared to high vigour seed lots (Table 3 and 4). As it can be seen from Table 3 for onions, low vigour seed lot (C) had the longest MGT, while the high vigour seed lots (B and F) had the shortest MGT (Table 3). The MGT as well as GE results can be helpful in further separating the intermediate vigour seed lots.

Exposure to different relative humidities as an alternative for ageing was valuable in separating seed lots of both crops based on their physiological stages of deterioration. As a result, a suitable ageing test can be performed based on the environmental conditions under which the seeds are planted. According to Rodo and Marcos Filho (2003), the use of saturated salt accelerated ageing using NaCl (RH75) was found to be successful for differentiating seed lots of onion that had similar normal germination percentages but different levels of vigour.

The emergence trial at 15°/25°C demonstrated a narrow range (12%). In the standard germination test (SGT) the range was only 10%, which is similar to the range obtained from the emergence trial at a favourable temperature (15°/25°C) (Table 3). However, for other emergence trials the germination percentage range was about 20%. Although all seed lots showed higher germination in the laboratory, there was a wide range in emergence percentage at non-favourable temperatures (winter and 30°C), indicating that they differed in vigour. Differences in emergence of seed lots that have similar germination percentages can be explained by differences in seed vigour (Hampton, 1981).

To differentiate seed lots with moderate vigour, the rate of germination parameters (MGT and GE) can be used. However, since rate of germination is highly temperature (Ellis & Roberts, 1980) and moisture dependent, it needs careful regulation to ensure accurate results. It is also important to note that in calculating GE and MGT, all seeds with emerged radicles were counted. A seed lot can have a short MGT or high GE even if there were few normal seedlings. Therefore, application of these tests as vigour tests without determining the standard germination percentage, may lead to incorrect conclusions.

NaCl (RH75) produced relatively consistent results as compared to other ageing conditions in terms of seed moisture content. In this test, unlike that of the standard AA no fungal growth was observed. NaCl can be used even with less precise temperature controlled incubators, since the relative humidity is constant (~75%) at a range of temperatures (2° - 50°C). Winiston and Bates (1960) suggested the use of NaCl to reduce variations introduced by fluctuations in temperature.

Table 5 Best models for predicting emergence of cabbage and onion planted at range of temperatures

Crop	Laboratory test (x)	Emergence trial (y)	Equation
Cabbage	10°C	Winter	$y = 0.9983x - 10.53$ ($r^2 = 0.88$**)
	RH32	15°/25°C	$y = 0.9806x + 9.8299$ ($r^2 = 0.93$**)
	10°C	30°C	$y = 0.5852x + 37.41$ ($r^2 = 0.92$**)
Onion	30°C	Winter	$y = 1.5252x - 51.537$ ($r^2 = 0.96$**)
	15°C	15°/25°C	$y = 0.9036x + 8.2453$ ($r^2 = 0.88$**)
	30°C	30°C	$y = 1.4529x - 41.108$ ($r^2 = 0.81$*)

*Significant at α=0.05, **significant at α=0.01.

Correlation between laboratory tests and emergence trials

Correlations between the laboratory (germination and vigour) test and emergence test results of cabbage and onion are shown in Table 4. For both crops, there was no significant difference in FEP between the two growth media. Hence correlations calculated with the mean FEP of the two growth media are reported.

There were highly significant (r^2 = 0.96) correlations between the germination percentages at 10°C and all emergence trials of cabbage (Table 4). Smith and Varvil (1984) reported the use of a cool test in predicting field performance under unfavourable conditions. Strydom and Van de Venter (1998) reported a good correlation between germination percentage only at 10°C and winter emergence of cabbage, but not under favourable planting conditions. The contrasting result could be since they used some seed lots with low (below 80%) germination percentages, while in the current study all seed lots had a standard germination of above 80% (Table 2).

Unlike cabbage, there was significant correlation between germination at standard temperatures of 15° (r^2 = 0.88) and 20°C (r^2 = 0.76), when onion seeds were planted at favourable temperature (15°/25°C). This proved that standard germination percentage is a reliable tool for predicting emergence of onion seed lots when planted under conducive environmental conditions (Tekrony, 2003). Germination at high temperature was correlated with unfavourable emergence trials (winter: r^2 = 0.96) and (30°C: r^2 = 0.88) and can be used when onion seeds are planted at adverse temperatures.

GC (r^2 = 0.78) correlated significantly with emergence trial of onion at 15°/25°C. The use of GC may be helpful to predict emergence of onion seed when planted under suitable environmental conditions. In case of very favourable environmental conditions, abnormal seedlings might develop into normal transplants. The use of GC may also avoid disagreement arising because of subjective assessment of normal seedlings (Matthews, 1980).

Germination rate parameters (GE and MGT) did not correlate with any of the emergence trials of cabbage. Similarly, Matthews (1980) reported a non-significant correlation between MGT and percentage emergence of cabbage seeds. For onion, GE had a significant correlation only with winter emergence trial of onion, but MGT did not correlate with any of the emergence trials.

All ageing results of cabbage, except for the standard AA (RH100) correlated with emergence trials at 15°/25° and 30°C with r^2 greater than 0.81 (Table 4). Powell (1995) reported non-significant correlations between standard AA and field emergence results of cabbage. The germination percentage after ageing with RH32 was correlated with emergence trials at 15°/25°C (r^2 = 0.93) and 30°C (r^2 = 0.91). For onions, all emergence test results did not correlate significantly with results from the standard AA (RH100). Similarly, Kraak *et al.* (1984) reported non-significant correlation between AA test results and field emergence percentage of onion. Germination results after ageing at RH75 and RH32 were significantly correlated with the results of the favourable (15°/25 °C) emergence trial with r^2 of 0.76 and 0.85 respectively. RH32 was also significantly correlated with winter emergence trial (r^2 = 0.83). The best models for predicting emergence of cabbage and onion at range of temperatures are shown in Table 5.

Conclusions

Germination percentages at non-standard temperatures and different ageing conditions can be used to separate seed lots according to their vigour levels. There was no significant difference in terms of percentage and rate of emergence between the two growth media (Hygromix and soil) used in this study. Hence, the results could be applicable for direct field planting of these vegetables seeds. Germination at 10°C (cabbage) and 30°C (onion), SSAA test using RH32 and R75 were the best to predict seedling emergence for both crops. Therefore, substitution of standard AA with SSAA not only gives good field estimation but also controls fungal growth. It is advisable to use NaCl since the relative humidity is constant at a range of temperatures. Standard germination percentage was a good tool for predicting emergence of onion seed lots when planted under conducive environments. However, under adverse environmental conditions, the standard germination test should be supplemented with other vigour tests.

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