Association between biometric characteristics of tomato seeds and seedling growth and development

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ABSTRACT

Background: The size and weight of tomato seeds depend on genetics and can be modified by environment and management. In some species, a strong relation has been described between physical aspects of the seeds and the quality of the corresponding seedlings, but this cannot be considered a general rule. The objective of this research was to identify any association between the biometric characteristics of tomato seeds and the growth and development of their seedlings.

Results: A total of 18 lots of hybrid tomato seeds were used (from indeterminate plants with round fruits), belonging to six varieties from two reproduction seasons. Each lot was evaluated for seed size and weight, and seed quality, in terms of the germination test (5 and 14 d after sowing). The number of normal roots emerged with a length above 2 mm was also evaluated at d 3, 4 and 5 after sowing. The results indicate that there was no association between seed size and weight and subsequent seedling emergence, and only weak correlations were found between the dry weight of the radicle and cotyledon and seed size.

Conclusion: There is little association between the physical characteristics of the seeds and the subsequent seedlings, making it impossible to propose the use of seed weight or size as a compliment to quality evaluation tests.

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1. Introduction

The current definition of seed quality includes physical aspects such as size and weight [1] because there is often an association between size and quality in agricultural species [2]. However, this statement depends on the type of seed in question and cannot be used as a general rule for all different groups of vegetables that are sold by the global seed industry. Most information has been gathered in regard to monocots, but their particular nature, especially in terms of anatomy, composition and metabolism, can be very different to other seeds [3].

Though most information that is available is in regard to cereals and other agriculture seeds, it can be noted that for tomato, Nieuwhof et al. [4] found that heavier seeds produced heavier plants, while Khan et al. [5] demonstrated a high level of association between seed weight and seedling dry weight. Van der Merwe et al. [6] included biomass, particularly of the radicle, as an indicator of seed quality.

In the field of seed quality evaluation, there is agreement that standard germination does not provide sufficient information, and as such the parameter vigour has been considered [7]. Though this variable is complex, it has been defined by analysts [8] as the sum of seed properties that lead to the rapid production of uniform seedlings under a wide range of field conditions. Upon further analysis of this definition, it can be seen that it includes early growth and development stages, firstly in association with germination and later with emergence. This type of evaluation coincides with the current trends in growth tests and seedling evaluation [1]. This definition makes no association between the physical aspects of the seeds and the behaviour of the seedlings.

Several authors have evaluated the connection between seeds and seedling quality over short periods, without looking beyond 14 d after sowing [9,10]. For tomato, Akbudak and Bolkan [11] evaluated the quality of seedlings after 3 and 7 d while Khan et al. [5] conducted evaluations at d 5, and 10. One objective of the current analysis is to reduce analysis time. As such, in order to support some seedling evaluation methods, the analysis of digital images has been used to improve objectivity [12,13,14,15].

Other authors have evaluated seedling length, without making any connection with the physical characteristics of the seeds, e.g. Sako et al. [12] and Kikuti and Marcos-Filho [16] respectively implemented and used total, hypocotyl and radicle length as the basis for estimating...
2.3. Germination test

Resolution of 300 dpi; the images were stored in jpeg format. The Packard model Precision Scan Pro 3.02 fl (SAr), and was obtained from digital images acquired with a Hewlett Packard 4670 vertical scanner with a resolution of 200 dpi. The evaluations were conducted only with germinated seedlings with a radicle length of ≥2 mm. Counts were made of the number of seedlings germinated 3, 4 and 5 d after sowing (S3d, S4d and S5d respectively) and then were converted to be expressed as percentages. Germinated seed length was measured 5 d after sowing and was broken down into radical length (RL), hypocotyl length (HL) and total length (TL). The dry weight of the germinated seedlings was taken 5 d after sowing and was broken down into radical dry weight (DWR), hypocotyl dry weight (DWH), cotyledon dry weight (DWC) and total dry weight (DTW). The dry weight was calculated by maintaining the seedling at a temperature of 70°C for 48 h.

2.4. Seedling emergence

The methodology is based on that described by Sako et al. [12] without calculating the vigour index developed by the author. Seeds from each lot were sown in four replications of 25 seeds on a double-layer of blue filter paper (Anchor Paper Co.) saturated with distilled water. The substrates were stored in transparent plastic boxes measuring 15 × 23 × 4 cm. The boxes were placed in a germination chamber at 25°C ± 0.1, without light. The boxes were placed vertically at 85°C. Digital images were taken of each repetition on a daily basis using a Hewlett Packard model 4670 vertical scanner with a resolution of 200 dpi. The evaluations were conducted only with germinated seedlings with a radicle length of ≥2 mm. Counts were made of the number of seedlings germinated 3, 4 and 5 d after sowing (S3d, S4d and S5d respectively) and then were converted to be expressed as percentages. Germinated seed length was measured 5 d after sowing and was broken down into radical length (RL), hypocotyl length (HL) and total length (TL). The dry weight of the germinated seedlings was taken 5 d after sowing and was broken down into radical dry weight (DWR), hypocotyl dry weight (DWH), cotyledon dry weight (DWC) and total dry weight (DTW). The dry weight was calculated by maintaining the seedling at a temperature of 70°C for 48 h.

2.5. Data extraction and digital image processing

The seed characterisation images were used to obtain data on the area, length and width of the seeds. The sprouted seedling images were used to obtain data on the lengths of the radicle and the hypocotyl. In both cases, this was done using the programme Sigma Scan Pro 5. Prior to this, all images were processed with calibration functions, intensity threshold, filter and number of objects.

2.6. Experimental design and data analysis

A fully randomised experimental design was used. The quantitative variables of the seed lots representing each variety were subjected to variance analysis and the means were compared using the Tukey or student’s t-test, with a level of significance of 0.05. Values expressed in percentages were transformed using the arcsine function \( \sqrt{x/100} \).

The association between two variables was determined via Pearson correlation with a level of significance of 0.05.

The variables of seed size and weight and their correlation to the dry weight of the sprouted seedlings were analysed using multiple regressions with a level of significance of 0.05.

Minitab 16, by Minitab Inc., was used for the statistical analysis.

3. Results and discussion

3.1. Seedling emergence

The emerged plants and their growth and development characteristics are presented as an alternative for evaluating quality through new vigour tests, as they satisfy the needs established by several authors for quick low cost analysis methods that are non-destructive and easy to implement within the seed industry [26].

As can be seen in Table 1, the emerged seedling showed significant differences between lots in three of the six varieties evaluated in the study; these were varieties H, I and J. This was the case for the different d after sowing, though it was more frequent on d 4 (S4d) and 5 (S5d). These results partially complement the information from the germination test (G), which is insufficiently sensitive to distinguish the quality of lots according to several authors [7,23].

Akbudak and Bolkan [11] identified the importance of seedlings at d 3 or 4 for differentiating the quality of tomato seed lots. In addition, the values from d 4 (S4d) onwards were higher than those obtained in
the germination test (G) with the exception of lot 4 of variety J. Seedling emergence increased by differing percentages depending on the time between sowing and observation. This coincides with Demir et al. [24], who studied bell peppers, finding association between early germination and longer and more homogenous seedlings.

With regard to the capacity to discern quality, it can be said that his existence of differences with regard to the present research shows the germination test partially differentiated between the lots from d 3 onwards, which was recently studied by Ferreira et al. [15]. With some large seeds, such as legumes [7,10]. However, Khan [23], who studied bell peppers, found a positive correlation between sowing and observation. This coincides with Demir et al. [24], who studied bell peppers, finding association between early germination and longer and more homogenous seedlings.

3.3. Seedling length

It can be seen in Table 2 that only the lots of variety F showed significant differences in RL and TL, while no differences were seen for all other lots. Sako et al. [12] studied the early utility of this variable for discerning seed quality, based on the notion that radicle and seedling growth (length) and the growth rate are direct components in defining seed vigour [8]. Thus, as with Oakley et al. [14], several different seed lots have been successfully ranked, particularly in lettuce and impatiens. Researchers such as Van der Merwe et al. [6] and Akbudak and Bolkan [11] have found the same in tomato. The existence of differences with regard to the present research shows that working with seeds with relatively low germination percentages (<87%, Table 1), the presence of seedling abnormalities can affect root length, while no differences were seen for DWR, DWH, DWC and DWT of the 18 tomato seed lots from six hybrid varieties.

Table 2

| Variety | Lot | RL (mm) | HL (mm) | TL (mm) | DWR (mg) | DWH (mg) | DWC (mg) | DWT (mg) |
|---------|-----|---------|---------|---------|----------|----------|----------|----------|
| F       | 1   | 39.90a  | 9.00a   | 48.90a  | 0.46a    | 0.58a    | 1.71a    | 2.75a    |
|         | 2   | 37.48a  | 8.25a   | 46.73b  | 0.45a    | 0.57a    | 1.56a    | 2.50ab   |
| G       | 3   | 35.90a  | 9.00a   | 45.90a  | 0.46a    | 0.57a    | 1.71a    | 2.75a    |
| H       | 4   | 34.85a  | 8.50a   | 44.38a  | 0.32a    | 0.46a    | 0.98b    | 1.76a    |
| I       | 5   | 34.48a  | 8.50a   | 42.98a  | 0.30ab   | 0.47a    | 1.09b    | 1.86a    |
| J       | 6   | 34.78a  | 8.50a   | 42.98a  | 0.30ab   | 0.47a    | 1.09b    | 1.86a    |
| K       | 7   | 34.75a  | 8.50a   | 42.98a  | 0.30ab   | 0.47a    | 1.09b    | 1.86a    |

Measurements followed by the same letter presented no statistical differences with a probability of 5%. CV: coefficient of variation.
lot of variety J. For the cotyledons, the dry weight (DWC) gave some differences between lots of varieties G and K. The DWT showed the cotyledons of variety J. For the cotyledons, the dry weight (DWC) gave some

Correlations between seed and seedling attributes. SW, SL, SWi, SAr, seedling emergence on d 3 after sowing (S3d), seedling emergence on d 4 after sowing (S4d), seedling emergence on d 5 after sowing (S5d), RL, HL, TL, DWR, DWi, DWC and DWT of the 18 tomato seed lots from six hybrid varieties.

| SW  | SL  | SWi | SAr | S3d | S4d | S5d | RL  | HL  | TL  | DWR | DWi | DWC |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.411 | 0.000 |     |     |     |     |     |     |     |     |     |     |     |
| 0.744 | 0.423 |     |     |     |     |     |     |     |     |     |     |     |
| 0.000 | 0.000 |     |     |     |     |     |     |     |     |     |     |     |
| 0.572 | 0.865 | 0.563 |     |     |     |     |     |     |     |     |     |     |
| 0.000 | 0.000 | 0.000 |     |     |     |     |     |     |     |     |     |     |
| -0.057 | 0.057 | -0.165 | 0.165 | -0.097 | 0.416 |     |     |     |     |     |     |     |
| 0.636 | 0.632 |     |     |     |     |     |     |     |     |     |     |     |
| 0.094 | 0.146 | 0.067 | 0.069 | 0.624 |     |     |     |     |     |     |     |     |
| 0.411 | 0.221 | 0.573 | 0.564 | 0.000 |     |     |     |     |     |     |     |     |
| 0.060 | 0.139 | -0.001 | 0.040 | 0.67 | 0.962 |     |     |     |     |     |     |     |
| 0.619 | 0.245 | 0.994 | 0.736 | 0.000 | 0.000 |     |     |     |     |     |     |     |
| -0.220 | 0.206 | -0.052 | 0.135 | 0.180 | 0.138 | 0.125 |     |     |     |     |     |     |
| 0.063 | 0.083 | 0.664 | 0.257 | 0.130 | 0.247 | 0.296 |     |     |     |     |     |     |
| 0.037 | 0.204 | 0.152 | 0.233 | -0.065 | 0.213 | 0.215 | 0.308 |     |     |     |     |     |
| 0.756 | 0.086 | 0.202 | 0.049 | 0.590 | 0.072 | 0.069 | 0.009 |     |     |     |     |     |
| -0.173 | 0.242 | 0.008 | 0.193 | 0.130 | 0.189 | 0.178 | 0.947 | 0.598 |     |     |     |     |
| 0.147 | 0.040 | 0.948 | 0.104 | 0.277 | 0.113 | 0.135 | 0.000 | 0.000 |     |     |     |     |
| 0.237 | 0.549 | 0.354 | 0.523 | 0.144 | 0.316 | 0.307 | 0.371 | 0.571 | 0.506 |     |     |     |
| 0.045 | 0.065 | 0.002 | 0.000 | 0.229 | 0.007 | 0.009 | 0.001 | 0.000 | 0.000 |     |     |     |
| -0.048 | -0.155 | -0.193 | -0.172 | 0.162 | 0.248 | 0.208 | 0.082 | -0.245 | -0.014 | -0.003 |     |     |
| 0.688 | 0.192 | 0.105 | 0.148 | 0.174 | 0.036 | 0.080 | 0.494 | 0.038 | 0.906 | 0.004 |     |     |
| 0.099 | -0.350 | -0.093 | -0.337 | -0.043 | -0.194 | -0.180 | -0.330 | -0.486 | -0.442 | -0.753 | 0.379 |     |
| 0.408 | 0.003 | 0.436 | 0.004 | 0.719 | 0.102 | 0.130 | 0.005 | 0.000 | 0.000 | 0.000 | 0.001 |     |
| 0.396 | 0.136 | 0.230 | 0.117 | 0.172 | 0.209 | 0.203 | 0.036 | -0.049 | 0.014 | 0.078 | 0.463 | 0.560 |
| 0.001 | 0.253 | 0.052 | 0.328 | 0.149 | 0.079 | 0.087 | 0.761 | 0.683 | 0.907 | 0.513 | 0.000 | 0.000 |

The first number in each cell indicates the Pearson coefficient of correlation. The second number in each cell indicates the p-value with an α-level of 0.05.

3.6. Association between biometric characteristics of the seeds and seedling dry weight

As can be seen in Table 3, there is very little correlation between the total of the biometric characteristics of the seeds and the physical aspects of the resulting seedlings. Fig. 1 includes only the statistically significant correlations between the physical attributes of the seeds and the resulting seedlings. Only total dry weight of the seedlings was lightly associated with seed weight (Fig. 1f). The dry weight of the radicles showed a weak positive association with the seed size characteristics (Fig. 1a, Fig. 1b and Fig. 1c). The dry weight of the hypocotyl was not correlated with their respective seeds (Table 3). The latter result is contrary to those of Khan et al. [5], who found positive association between seed weight and radicle and hypocotyl weight for tomato seeds. The dry weight of the cotyledon was negatively correlated with seed area and seed length (Fig. 1d and Fig. 1e). These results can be explained by the work of Orsi and Tanksley [29], who found that the relation between the components of the seed (germ and endosperm) and its composition influences its behaviour.

Regarding the relation between the size and weight attributes of the seeds and the dry weight of the seedlings they produce, multiple regression showed that this association is low (Table 4). Thus, the highest coefficient was obtained for the model that represents how the DWR depends on the SL, SWi and SAr of the seeds. The DWC and the total DWT also present a relatively low R², though only the DWT showed association with the SW. These results demonstrate that there are other factors in the seeds that also determine quality, as seen in the definition of vigour [8]. Many authors have recently associated quality more with seed composition [3].

3.7. Association between seedling emergence and dry weight

The DWR was the only part of the seedlings to show positive correlation with seedling emergence on d 4 (S4d) and d 5 (S5d) after sowing (Fig. 1g, Fig. 1h). The DWR was also associated with the length of each of the parts and the total length of the seedlings (Fig. 1i, Fig. 1j, Fig. 1k). Bertholdsson and Brantestam [27] found a positive association between the weight and length of the radicle and seed quality in cereals. The DWH showed no association with seedling characteristics, while the dry weight of the cotyledon (DWC) was inversely related to total TL (Fig. 1l). The latter observation coincides with Bertholdsson and Brantestam [27].

3.8. Association between seedling emergence per observation day

There was association between seedling emergence on the 3 d of observation (Fig. 1m, Fig. 1n, and Fig. 1o), most notably on d 4 (S4d) and d 5 (S5d), with correlation coefficients above 0.90. As described previously by several researchers, the main germination events take place from 48 to 96 h after sowing [18,19,20], and as such mainly undamaged plants are to be expected [23]. Akbudak and Bolkan [11] found that the germination percentages at d 3 and 4 were more efficient for predicting seedling emergence, thus allowing the proposal of an early methodology for evaluating tomato seed quality.

4. Conclusions

Finally, it should be noted that the present research found little association between the physical characteristics of the seeds and the subsequent seedlings, making it impossible to propose the use of seed weight or size as a complement to quality evaluation tests.
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Conflict of interest

No conflict interest.

Table 4

| Y         | Significance of the equation (p < 0.05) | \( R^2 \) |
|-----------|----------------------------------------|---------|
| DWR       | \( y = -2.984 + 0.47 \cdot SL - 0.72 \cdot SWi + 0.031 \cdot SAr \) | 0.30    |
| DWC       | \( y = 2.921 - 0.35 \cdot SL - 0.088 \cdot SAr \) | 0.20    |
| DWT       | \( y = 1.007 + 0.21 \cdot SL + 0.386 \cdot SW \) | 0.14    |

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