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High Nitrogen Fertilization Decreases Seed Weight but Increases Longevity in Tomato Seeds

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Abstract: Nitrogen fertilization is a key practice in agriculture and its effects on yield and quality of most commodity products are widely known. However, the response of seed production to N fertilization, especially with regard to its effects on seed quality, is still poorly understood. The objective of this study was to determine the effect of N fertilization on tomato seed yield and quality. Six quality attributes were assessed (weight, standard germination, germination rate under normal and adverse conditions, dormancy and longevity) in tomato cv. Moneymaker plants fertigated with one of three nutrient solutions differing in their N concentration: 5, 15 or 25 mM. Seed weight decreased by 4% with increasing N fertilization while standard germination and mean germination time did not vary among treatments, with average values of 89.7% and 6.2 days, respectively. The percentage and rate of germination decreased when seeds were imbibed in solutions with reduced osmotic potential; however, this effect was less pronounced in seeds from the 25 mM treatment, indicating a lower dormancy. When germination was evaluated after accelerated aging, seeds from the high N fertilization treatment showed greater longevity. These results contribute to optimizing fertilization practices for the production of high quality tomato seeds.

Keywords: seed germination; seed quality; dormancy

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1. Introduction

Nitrogen (N) fertilization is one of the main practices in horticulture and its effects on yield and quality for most commodity crops are widely known. Specifically, for the tomato, N fertilization directly affects yield components, such as fruit weigh t and number, and quality parameters like soluble solids content [1,2]. Optimum fertilization for most important horticultural species, including the tomato, has been widely studied and crop demands are well-known. However, in crops intended for seed production, fertilization is managed similarly to crops cultivated for fresh produce [3], with little understanding of the effects of fertilization on seed quality attributes such as dormancy and longevity, which are essential for sustainable production of most economically-important crops [4].

Seed yield in tomato cv. Moneymaker has been reported to increase when N fertilization increased from 50 to 100 g·N m^{-2}, in terms of higher fruit yield and thousand-seed weight (TSW) [5]. Increases in TSW with increasing N fertilization have also been reported in other studies. For instance, Eryuce and Aydin [6] observed that an increase in tomato TSW occurred between 0 and 180 kg N ha^{-1}, but as fertilization increased to 240 kg N ha^{-1}, TSW decreased. Similarly, increasing nitrate concentration in the nutrient solution for tomato cv. Moneymaker increased TSW up to a nitrate concentration of 20 mM, above which TSW decreased [7].

With regard to the effect of N fertilization on seed quality, a decrease in standard germination has been observed in species such as lettuce and tomato when overfertilization occurred [6,8]. Moreover, absence of nitrate in the fertilization of *Arabidopsis* and tomato plants has been reported to cause a decrease in standard germination [7,9]. The effect of

N fertilization on seed vigor has been studied with two main approaches: germination rate and germination under adverse conditions. First, in lettuce [8] and the tomato [6], germination rate reduction has been reported under conditions of N overfertilization. Secondly, germination under adverse conditions (salt, mannitol, abscisic acid, high temperature) has been increased in seed produced with higher N fertilization in *Arabidopsis* [9] and tomato [7].

Also relevant for seed quality are dormancy and longevity [4]. Tomato seed (cv. Moneymaker) exhibits physiological dormancy which is strongly influenced by the growing environment of the mother plants [10]. Nitrate promotes germination in many plant species, including the tomato [11,12]. This effect was observed in the tomato by priming it with nitrate-containing compounds [13,14]. However, no research is available about the effect of nitrate fertilization on tomato seed dormancy. Studies with *Arabidopsis* showed that increased nitrate nutrition in the mother plant increases nitrate concentration in seeds and reduces dormancy [9,15]. Regarding longevity, research on how fertilization of the mother plant affects longevity is still limited. Albornoz et al. [8] reported that intermediate doses of N fertilization (5 mM) in lettuce mother plants produced seeds with greater longevity.

The objective of this study was to determine the impact of N fertilization on tomato seed quality based on six quality attributes: seed weight, standard germination, germination rate under normal and adverse conditions, dormancy, and longevity. Simultaneous evaluation of these parameters has not yet been reported for the tomato. The present study offers comprehensive insight into the quality attributes of tomato seed produced under three N fertilization doses.

2. Materials and Methods

2.1. Plant Material and Growth Conditions

Tomato (*Solanum lycopersicum* L. cv. Moneymaker) seeds were sown in polyethylene trays containing a mix of peat and perlite (3/1, *v*/*v*). Once seedlings reached 1–2 true leaves (28 days after sowing), they were transplanted into 0.35 L containers with compost (Tierra Biológica Compost, Anasac Jardín, Chile). Plants with 3–5 true leaves (60 days after sowing) were transplanted on 29 December 2020 outdoors into 4 L pots using a mix of peat and perlite (3/1, *v*/*v*).

Plants were fertilized using a Hoagland solution until the flowering of the second cluster, 17 days after transplanting, at which point the fertilization treatments began. Plants were pruned and trained to one stem and tipped after the fourth cluster. The first cluster was pruned, so plants produced fruits only on their second, third and fourth cluster. Fruit was harvested between 60 and 120 days after transplanting, at the red color stage. Average daytime and nighttime temperature and relative humidity were 23.8 °C and 51%, and 15.9 °C and 72.7%, respectively.

2.2. Treatments

Plants were fertigated with one of three nutrient solutions differing in their N concentration: 5, 15 or 25 mM. The supply of P, K, Ca, Mg and S was similar in all treatments, with concentrations of 1, 5, 4.5, 2 and 2 mM, respectively (Table 1). Each nutrient solution was mixed directly into a 240 L tank using reverse osmosis water, and pH was adjusted to 5.8 $\pm$ 0.2 using phosphoric acid.

Plants were distributed using a randomized complete block design with four replicates and three plants per experimental unit. Each block corresponded to a row, with 1.2 m between rows and 0.3 m between plants within the row. Each pot received 2.1 L of nutrient solution daily, distributed in eight applications between 8:00 a.m. and 6:00 p.m. Volume was reduced to 0.9 L per pot from 80 days after transplanting and onward. Flowers were self-pollinated naturally.

Table 1. Fertilizer content in the nutrient solution of each treatment.

Treatment (N Concentration)	Fertilizer Concentration (mM)	EC (dS m^{-1})
5 mM	4 KCl, 2 $CaCl_2$, 2.5 $Ca(NO_3)_2 \times 4H_2O$, 1KH_2PO_4, 2 $MgSO_4 \times 7H_2O$	2.2
15 mM	5 NH_4NO_3, 4 KCl, 2 $CaCl_2$, 2.5 $Ca(NO_3)_2 \times 4H_2O$, 1 KH_2PO_4, 2 $MgSO_4 \times 7H_2O$	3.0
25 mM	10 NH_4NO_3, 4 KCl, 2 $CaCl_2$, 2.5 $Ca(NO_3)_2 \times 4H_2O$, 1 KH_2PO_4, 2 $MgSO_4 \times 7H_2O$	3.8

Micronutrients were supplied to all treatments in the following concentrations (μM): 45 Fe, 31 Zn, 27 Mn, 69 B, 4 Cu, 0.3 Mo.

At harvest, fruits within an experimental unit were combined by flower cluster number. Once fruit traits were measured, seeds and pulp were manually extracted, placed in 0.3 L beakers, and fermented at ambient temperature (20 °C) for 48 h [16]. The seeds were then washed with water and wind-dried at 30 °C for 2 h. Dried seeds were stored in paper bags and placed in a desiccator for 48 h. Seeds were then stored in Petri dishes at 20 °C until evaluation.

2.3. Measurements

2.3.1. Fruit and Seed Weight

Fruits were weighed individually, and the soluble solid content of the pulp was determined using a digital refractometer. Average seed weight (thousand-seed weight, TSW) in each replicate was determined by weighing eight samples of 100 seeds each [17]. Seed nitrate content was measured by colorimetry after water extraction and reaction with salicylic plus sulfuric acid [8].

2.3.2. Standard Germination

All seed quality tests were carried out using seeds obtained from the third cluster of each plant. Standard germination was evaluated according to the ISTA protocol [17], using 400 seeds per treatment (100 seeds per block in four subsamples of 25) at 20 °C without light for 16 h and 30 °C with light for 8 h. Seeds were sown in 90 mm Petri dishes over two layers of 70 g m^{-2} filter paper (Macherey-Nagel, Düren, Germany) saturated with distilled water. After 5 days, a solution of Captan (1.3 g a.i. L^{-1}) fungicide was sprayed on the seeds. Counting was carried out 14 days after sowing, determining normal seedlings, abnormal seedlings, fresh seeds, and dead seeds.

2.3.3. Physiological Germination

Seed physiological germination (PG; radicle protrusion larger than 2 mm) was evaluated in distilled water or solutions at different water potentials prepared with polyethylene glycol (PEG) according to the equation proposed by Michel [18]. Five months after harvest, PG was evaluated in water and a −0.1 MPa solution in two subsamples of 50 seeds per replicate. Eight months after harvest, PG was evaluated in water and −0.10, −0.15, and −0.20 MPa solutions, with 50 seeds per replicate.

All PG evaluations were carried out in 90 mm Petri dishes, over two layers of filter paper saturated with distilled water or the PEG solution, at 20 °C, without light, with Captan solution sprayed on the seeds at sowing. Daily counts were performed and germination percentage (%G) and mean germination time (MGT) were calculated according to Equations (1) and (2), respectively.

$$\%G = (\text{number of germinated seeds on day } 14/\text{total number of seeds}) \times 100 \quad (1)$$

$$MGT = \sum_{i=1} (\text{number of seeds germinated on day } i \times i)/(\text{total germinated seeds}) \quad (2)$$

2.3.4. Seed Longevity

A saturated salt accelerated aging (SSAA) test was conducted [19]. Seeds were placed in plastic containers at 96% relative humidity using a saturated solution of K_2SO_4 [20]. Containers were placed in a water-jacketed incubator (model 3015, Sheldon Manufacturing, Cornelius, OR, USA) at 41 °C. For each treatment, 50 seeds per replication were aged

during 5, 10, 15, 20 or 26 days. After aging, seed PG was evaluated in distilled water as described previously.

For the assessment of longevity, the initial viability or Ki value from Equation (3) was calculated for seeds from each experimental unit,

$$v = Ki - p/\sigma \quad (3)$$

where "v" is the percentage of germination, expressed in probit units, after "p" days of aging, and $1/\sigma$ represents the fraction of seeds (in probit) that lost viability during the "p" period of time [21]. The time when the seed lost 50% of its germination (T50) was calculated using a linear interpolation for germination values around 50% for each replicate.

2.4. Statistical Analysis

Germination variables were analyzed using generalized linear models with logit link and binomial distribution. All variables were evaluated by ANOVA, and when significant differences were detected ($p < 0.05$), mean comparison was performed using Tukey's test ($\alpha = 0.05$). Analyses were carried out using R statistics software (v.4.1.1, Vienna, Austria) through the RStudio console.

3. Results

3.1. Fruit Yield and Quality

Fruit weight decreased significantly ($p < 0.001$) with increasing N fertilization, with values of 72.9, 60.6 and 53.5 g for fruits produced in plants from the 5, 15 and 25 mM N treatments, respectively (Figure 1A). In contrast, a significant increase ($p < 0.002$) in soluble solid content of fruits was observed as N fertilization increased. For fruits from the 5, 15 and 25 mM treatments, soluble solid content was 5.6, 6.1 and 6.4° brix, respectively (Figure 1B). Although higher fruit yield per plant of 759 g was obtained with the 5 mM treatment, differences were not significant compared to the 15 and 25 mM treatments ($p = 0.210$), in which fruit yield per plant was 566 and 607 g, respectively (Figure 1C). The number of fruits per plant was not significantly different among treatments ($p = 0.491$). However, plants from the 25 mM treatment obtained 11.2 fruits on average, higher than the 5 and 15 mM treatments which obtained 10.3 and 9.2 fruits per plant, respectively (Figure 1D).

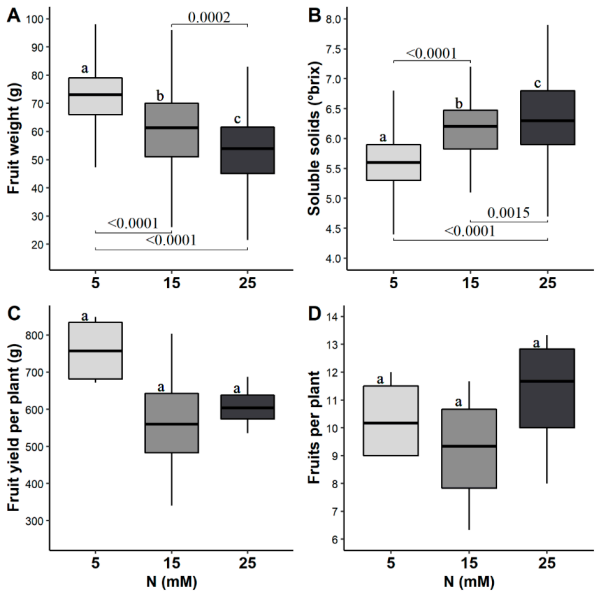

Figure 1. Fruit yield and quality from tomato plants fertigated with solutions of 5, 15 or 25 mM nitrogen (N) concentration. (**A**) Fruit weight (g); (**B**) Soluble solids (°brix) of fruit pulp; (**C**) Fruit yield per plant (g); and (**D**) Number of fruits per plant. Different letters represent a significant difference ($p < 0.05$). Numbers above the brackets represent *p*-values for contrasts between treatments.

3.2. Seed Yield and Nitrate Content

Seed weight decreased with increasing N fertilization ($p < 0.006$). Seeds from the 25 mM N treatment had the lowest TSW of 3.05 g, while the 15 and 5 mM treatments had a TSW of 3.14 and 3.19 g, respectively (Figure 2A). Although no significant differences in seed yield per plant were found ($p = 0.633$; Figure 2B), the 5 mM N treatment had a mean yield of 16.1 g per plant, more than 10% higher than the 14.1 and 14.4 g per plant of the 15 and 25 mM treatments, respectively. Seed nitrate content was also not affected by N fertilization ($p = 0.909$; Figure 3B).

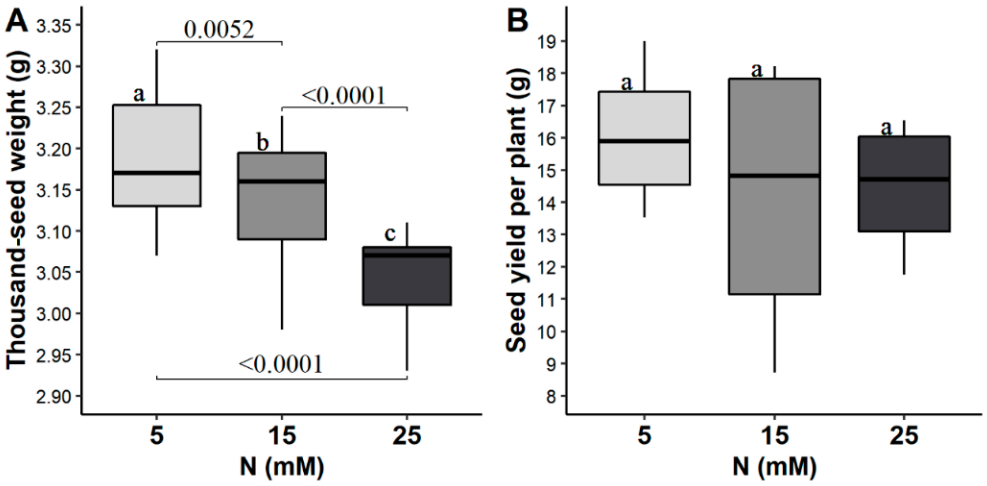

Figure 2. Seed weight (**A**) and seed yield per plant (**B**) from tomato plants fertigated with solutions of 5, 15 or 25 mM nitrogen (N) concentration. Different letters represent a significant difference ($p < 0.05$). Numbers above the brackets represent *p*-values for contrasts between treatments.

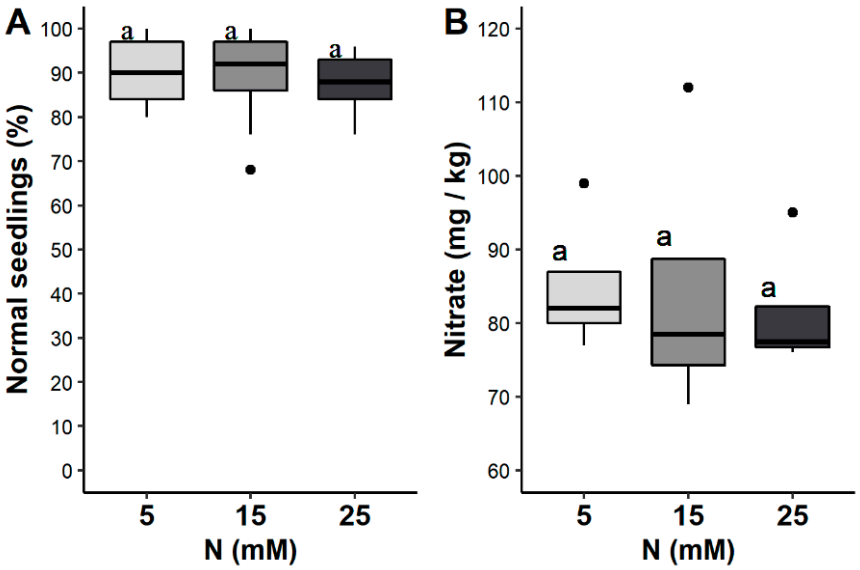

Figure 3. Normal seedlings percentage (**A**) and nitrate content (**B**) of seeds from tomato plants fertigated with solutions of 5, 15 or 25 mM nitrogen (N) concentration. Different letters represent a significant difference ($p < 0.05$). Dots represent outliers.

3.3. Standard and Physiological Germination

Nitrogen fertilization had no significant effect on standard germination (normal seedlings percentage; $p = 0.664$), which averaged 89.7% (Figure 4A).

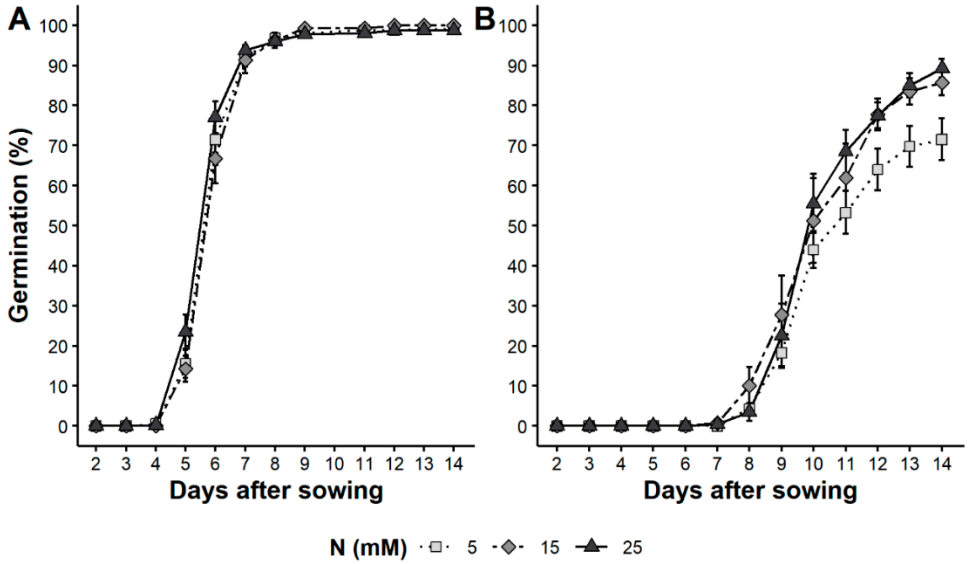

Figure 4. Germination curves at five months since harvest of seeds from tomato plants fertigated with solutions of 5, 15 or 25 mM nitrogen (N) concentration. (**A**) Germination in water (Ψ = 0 MPa). (**B**) Germination in −0.10 MPa water potential solution. Data are an average of four replicates, with two sub-samples of 50 seeds each, and bars represent standard error.

Five months after harvest, PG was evaluated in both water and a −0.10 MPa solution (Figure 4). No significant differences were found for PG in water, with all three treatments obtaining over 98% germination ($p = 0.921$; Figure 4A). However, germination at −0.10 MPa showed differences in %G, which was 71.5% in the 5 mM N treatment, significantly lower than in the 15 and 25 mM N treatments at 85.8% and 89.3%, respectively ($p = 0.003$; Figure 4B). Furthermore, germination in negative water potential both decreased %G and increased germination time (MGT) with respect to germination in water (Table 2). However, no significant differences were found between treatments for MGT ($p = 0.963$).

Table 2. Germination percentage and mean germination time (MGT) of tomato seeds from all nitrogen fertilization treatments, evaluated for different water potential solutions and times (5 or 8 months after harvest). Different letters represent significant differences according to Tukey test ($p = 0.05$). Lowercase letters represent differences between water potentials for each evaluation time. Capital letters represent differences between evaluation times for each water potential.

Parameter	Evaluation Time	Water Potential (MPa)			
		0	**−0.10**	**−0.15**	**−0.20**
Germination (%)	5 months	99.3 a A	82.2 b B	-	-
	8 months	98.3 a A	98.8 a A	99.3 a	93.8 b
MGT (days)	5 months	6.2 b A	10.5 a A	-	-
	8 months	4.9 d B	5.7 c B	6.6 b	7.3 a

Eight months after harvest, physiological germination was evaluated in water and three water potential solutions, −0.10, −0.15 and −0.20 MPa (Figure 5). No significant differences in %G were found when evaluated in water, −0.10 and −0.15 MPa solutions ($p = 0.130$, 0.361 and 0.651, respectively). However, %G for the 15 mM N treatment was significantly lower than the other treatments when evaluated at −0.20 MPa ($p < 0.001$), with values of 95.5%, 88.0% and 98.0% for the 5, 15 and 25 mM N treatments, respectively.

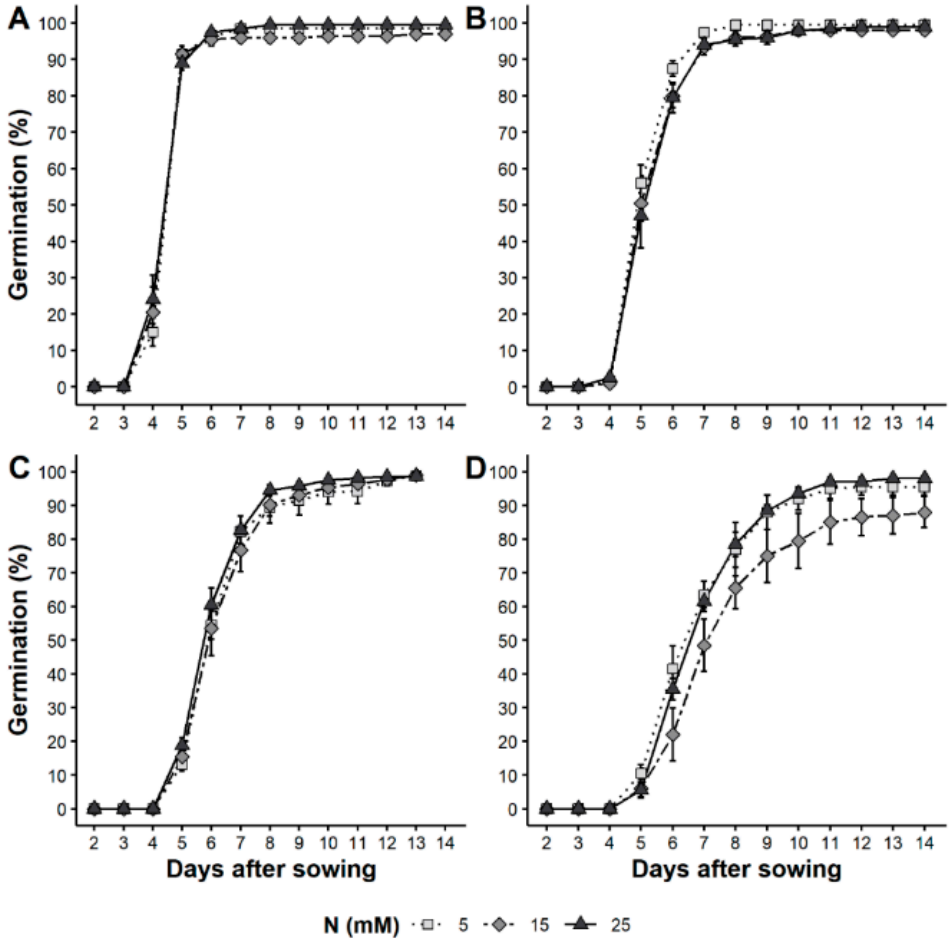

Figure 5. Germination curves after eight months from harvest of seeds from tomato plants fertigated with solutions of 5, 15 or 25 mM nitrogen (N) concentration. (**A**) Germination in water (Ψ = 0 MPa). (**B**) Germination in −0.10 MPa water potential solution. (**C**) Germination in −0.15 MPa water potential solution. (**D**) Germination in −0.20 MPa water potential solution. Data are an average of four replicates, with two sub-samples of 50 seeds each, and bars represent its standard error.

More negative water potential solutions significantly increased MGT for all N treatments ($p < 0.001$; Table 2) with no significant differences between treatments ($p = 0.922$, 0.071, 0.506 and 0.133, respectively, for germination in water, −0.10, −0.15 and −0.20 MPa solutions). A significant reduction in MGT was observed for all treatments when seeds were evaluated at eight months after harvest compared to the evaluation at five months after harvest ($p < 0.001$; Table 2). The %G increased when evaluated in the −0.10 MPa solution at eight months after harvest compared to the evaluation at 5 months ($p < 0.001$; Table 2).

3.4. Longevity

The highest N dose increased seed longevity. When germination was evaluated after 20 and 26 days of accelerated aging, seeds from the 25 mM N treatment showed significantly higher %G than seeds from the lower doses ($p < 0.001$) (Figure 6). No significant differences were found in T_{50} ($p = 0.081$); however, T_{50} was higher in the 25 mM N treatment than in the 15 and 5 mM N treatments, at 21.4, 17.5 and 19.6 days, respectively.

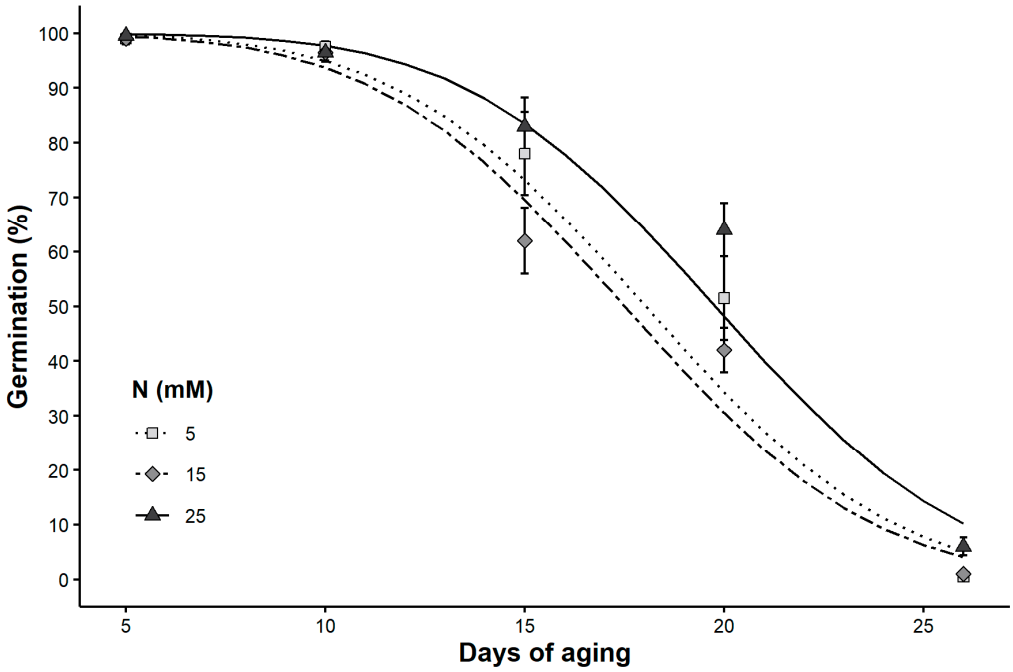

Figure 6. Germination after different periods of accelerated aging (41 °C and 96% RH) of seeds from tomato plants fertigated with solutions of 5, 15 or 25 mM nitrogen (N) concentration. Data are an average of four replicates of 50 seeds each and bars represent its standard error. Aging curves were fitted by probit analysis of the data, according with Equation (3), with a common standard deviation (σ) of 4,89 days and Ki values of 3.69, 3.58, and 4.04 for seeds from the 5, 15, and 25 mM N treatments, respectively.

The probit model was fitted to identify differences in seed longevity. This model allows the calculation of the K_i value, which corresponds to the intercept of viability (or germination) loss curves on a probit scale, and represents differences between different seed groups in terms of their potential longevity [21]. Ki values for the 5, 15, and 25 mM N treatments were 3.69, 3.59 and 4.03, respectively, with a significant difference between the 15 and the 25 mM N treatments (p = 0.049).

4. Discussion

4.1. Fruit Yield and Quality

In the present study, neither fruit yield nor fruit number per plant varied significantly with N doses between 5 and 25 mM. Increasing N supply up to 250 kg ha^{-1} improves tomato yield while further applications reduce marketable yield [1,2,5,22,23]. Further increasing N supply to tomato plants results in an increase in aboveground biomass, but partitioning towards fruit is reduced [24,25] because the leaf N sink is strengthened and the synthesis of N and sugar transporters moving these compounds from leaves to fruits is reduced [26].

Soluble solid content increased with N fertilization, in agreement with Agius et al. [27] who reported a yield decrease and soluble solid content increase in tomato fruits exposed to varying EC values in nutrient solutions. Other researchers have shown increases in soluble solids in tomato fruits from plants exposed to high doses of N, resulting from an enhancement in the synthesis of amino acids and proteins but a reduction in sugar accumulation [28]. Therefore, the increase in N availability within the plant triggers an increase in the consumption of sugars which are converted into organic acids [29]. Fruit acidity was not evaluated in our study and therefore it is not possible to confirm this effect.

4.2. Seed Yield and Weight

Seed yield represents an important issue for the seed industry, and therefore many practices carried out in seed production aim to improve seed yield. Nitrogen fertilization had no significant effect on seed yield. However, a significant decrease in seed weight (TSW) was observed. Increases in tomato seed yield in plants exposed to low-to-medium N fertilization have been previously reported [5,30], but no evidence was found in the literature regarding tomato seed yield under high N fertilization. Tomato seed weight increases with increasing N fertilization [5], but beyond some thresholds (180 kg N ha^{-1} or 20 mM N) TSW drops [6,7]. This effect is related to an osmotic effect that limits the export of carbohydrates to the seeds, as previously reported in lettuce [8]. Although no statistical significance was found, seed yield was ≈1.5 g per plant lower in the highest N treatments compared to the 5 mM N treatment, a reduction of almost 10%.

4.3. Seed Physiological Quality

Standard germination is the most commonly-applied seed physiological quality test because of its reproducibility [31,32]. Several studies in tomato plants have evaluated the effect of N fertilization on physiological germination (radicle protrusion), reporting that both high and absent N fertilization rates negatively affect germination [6,7]. However, the results of this research show no significant effect of N fertilization on standard or physiological germination in water, suggesting that both attributes are insensitive to large variations in N rate supply.

Given that field conditions are less favorable for seed germination than controlled laboratory conditions, standard germination generally overestimates the performance of seeds in the field [31]. A more comprehensive seed quality parameter is vigor, which considers the speed and uniformity of emergence and development of normal seedlings [32]. In our study, vigor was evaluated based on germination rate (MGT), which showed no significant differences when assessed in water at either 5 or 8 months after harvest. However, when physiological germination was tested under suboptimal conditions (low osmotic potential), differences among treatments were detected, providing support for this method of seed vigor assessment [33]. When tested in solutions with reduced osmotic potential, seeds from the 25 mM N treatment had a significantly higher %G than the 5 mM N treatment when tested at 5 months after harvest (−0.10 MPa solution) and the 15 mM N treatment when tested at 8 months after harvest (−0.20 MPa). These results are consistent with observations in *Arabidopsis* and the tomato, where germination under osmotic stress (mannitol and salt) showed that higher N concentrations increased %G [7,9]. This suggests that higher N fertilization in tomato mother plants positively relates to seed vigor, possibly because of a higher amino acid content in the seed which improves germination under stress conditions [7]. The osmotic effect cannot be ruled out, because imbibition is caused by the difference in water potential between the seed and the surrounding solution [34], meaning that seeds with higher solute content present a larger water potential gradient with the solution, allowing germination under low water potential.

Seed longevity corresponds to the time that seeds remain viable [35] during storage. It is acquired during seed development [34] and is considered one of the most sensitive attribute of seed vigor [32,34], commonly evaluated using accelerated aging tests [31,32,36]. The initial viability, or K_i value, derived from the model proposed by Ellis and Roberts [21], was a valid parameter for comparing seed longevity among treatments. These authors noticed that different seed lots stored in similar environments can lose viability at different rates, with little change in the viability for the initial storage period. Then, the loss of viability follows a sigmoidal curve, where K_i represents the initial quality or potential longevity of a given seed lot [21,34]. In our study, the estimated Ki value, or potential longevity, of seeds from plants with high N fertilization was significantly higher than in seeds from the other treatments. These results are consistent with those reported previously in *Arabidopsis* [9] but are contradictory to those reported for lettuce [8]. It is widely known that the environmental conditions in which the mother plant grows affect seed longevity;

however, research on the specific effect of nutrition and on the mechanisms involved in such regulation is still limited [37,38]. Studies carried out on pepper and peas suggest that higher seed quality and longevity are associated with higher proline content in the seeds [39,40]. Since higher doses of N fertilization favor the accumulation of amino acids in the seeds, including proline, this could be a possible explanation for the effect of N fertilization on tomato seed longevity observed in our study. Finally, these results support the suggestion that longevity, measured by the accelerated aging test, is a sensitive attribute for evaluating seed vigor.

4.4. Dormancy and Nitrate Content

Seed dormancy is the phenomenon in which viable seeds under favorable environmental conditions do not germinate or their germination is delayed [41,42], thus affecting seed vigor [4]. Tomato seeds present physiological dormancy controlled by the concentration of abscisic acid (ABA) in the embryo [10,34]. In the present study, physiological dormancy was observed in seeds from all treatments, which is evident when evaluating germination at 5 and 8 months after harvest. Seeds evaluated in water 8 months after harvest showed a lower germination time (MGT) than seeds evaluated 5 months after harvest. Furthermore, when germination was evaluated in a −0.10 MPa solution, MGT was lower and %G higher in seeds evaluated at 8 months after harvest. This increase in seed germinability is explained by after-ripening, or the gradual loss of physiological dormancy in the dry seeds of the tomato during storage at ambient temperature [4,34]. These results agree with previous reports using the tomato where ABA content in the embryo decreases with time, allowing for higher germination over time [43,44].

Germination under negative water potentials is functionally similar to the dormancy effect, as described by the hydrotime model [34]. Therefore, the increase in %G in seeds from the highest N treatment evaluated under negative water potentials is consistent with a decrease in seed dormancy. However, this effect was much lower than the after-ripening time effect. Research with *Arabidopsis* reports that nitrate nutrition of the mother plant affects seed dormancy [15] but no evidence was found for this in the tomato except for an increase in germination speed [5,45]. Three possible explanations for this result are discussed below: nitrate function, protein content, and seed structure.

First, nitrate stimulates germination and promotes dormancy release by altering ABA metabolism [11,41,46]. This effect has been documented with external applications of nitrate during germination. However, some evidence shows that high nitrate supply to *Arabidopsis* mother plants reduces seed dormancy by increasing endogenous nitrate in the seed [15,47]. Similar reports exist for the tomato [7] but no significant differences in seed nitrate content were found in our research. Secondly, higher N fertilization may be related to higher seed protein content which has been related to rapid germination [45]. Unfortunately, seed protein content was not evaluated in our study. Thirdly, seed structure is involved in dormancy, as evidenced by the lower dormancy shown in lighter seeds with thinner testa [48]. This is a plausible explanation since seeds from the 25 mM treatment had both significantly lower weight and dormancy.

Finally, seeds from the higher N fertilization treatment showed less dormancy and longer longevity. This result suggests a negative relationship between longevity and dormancy as previously documented in *Arabidopsis* [47], though most studies provide evidence to the contrary [34]. A negative correlation between longevity and dormancy is explained by seed-coat-imposed dormancy because the testa protects the embryo from deterioration but at the same time reduces the imbibition required for germination [37,44]. Our results provide evidence that the decrease in dormancy resulting from higher N fertilization was not related to seed structure but possibly to a chemical signal such as nitrate or another not evaluated in this research.

5. Conclusions

In conclusion, the higher dose of N fertilization supply to tomato mother plants reduced seed weight but did not negatively affect physiological seed quality. Only in very stringent tests did the higher nitrogen fertilization treatment show differences with the low and intermediate nitrogen treatments, specifically in terms of lower dormancy and longer longevity. Results from this research contribute to optimizing fertilization practices for the production of high quality tomato seeds.

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