Philippine Journal of Crop Science (PJCS) August 2025, 50 (2): 38-45

https://doi.org/10.63568/pjcs.v50i2.1530

Full Paper

Effects of Irradiated Carrageenan Biostimulant and Water-Based Enhancements on the Germination and Seedling Performance of Commercial F1 Hybrid Tomato

Fredelino E. Vecina Jr[1*], Sancho G. Bon[2], Hazel Anne F. Makahiya[2] Maria Fatima O. Mercado[2], and Annalissa L. Aquino[2*]

[1]Department of Crop Science, College of Agriculture, Food, Environment and Natural Resources, Cavite State University, Indang Cavite, 4122, Philippines; [2]Institute of Crop Science, College of Agriculture and Food Science, University of the Philippines Los Baños, College, Laguna, 4301 Philippines.
[*]Corresponding authors: fred.vecina@cvsu.edu.ph and alaquino1@up.edu.ph

Seeds of commercial F1 hybrid tomato varieties Fantastic F1 and Diamante max F1 were subjected to water and irradiated carrageenan biostimulant (ICB) treatments. It was aimed at determining the efficacy of the different treatments and the response of hybrid tomato seeds as measured by different germination and seedling quality indicators. Results showed that treatments significantly improved all indicators for Diamante Max across treatments. Similar results were obtained for Fantastic except for percent germination and germination index, which were not statistically different across treatments. ICB treatments were generally better than water treatments, though increasing rate of ICB showed reduction in improvement. Nonetheless, 1% ICB solution yielded the maximum values across indicators in both seed lots. In comparison to untreated seeds, 1% ICB differed by 8.80% - 183.56% on Diamante Max and 6.25% - 78.2% in Fantastic across indicators. Thus, ICB based seed priming was shown to improve germination and seedling indicators in hybrid tomato varieties. While some inconsistent observations were attributed to experimental limitations. Recommendations are forwarded.

Keywords: biostimulants, irradiated carrageenan, seed quality, seed enhancement, seed priming, tomato

INTRODUCTION

Scientifically named *Solanum lycopersicum* by Linneaus, tomato is the 368th most traded product in the world valued at USD 10.4 B in 2022. Worldwide, export is topped by Mexico while USA made the top importer (oec.world 2024). While China is the top producer in 2021 accounting for 36% of the total global production (rankingroyals.com 2024). Tomato is well-known as a fruit vegetable packed high amounts of nutrients such as the antioxidant lycopene, minerals, vitamins, carotenoids, phytosterols, phenolics and other phyto-nutrients, beneficial to promote good health and general well-being (Ali et al. 2020). Thus, a crop as important as tomato, agricultural production inputs such as quality seeds are necessary if not absolute. In some situation however, an interplay of factors may result in seed quality issues such as poor germination resulting to inferior crop performance. This scenario is likely for small farmers relying on commercial retailers of vegetables seeds sources where stocks are not optimally stored. In the Philippine context, tomato is one of the top vegetable crops grown nationwide, with an annual production of approximately 262,000 MT in 2023, according to the Philippine Statistics Authority (PSA 2024). Major producing regions include Ilocos Region, Central Luzon, CALABARZON, and Northern Mindanao. Fantastic F1 and Diamante Dmax F1 are commonly available hybrid varieties in local agricultural supply stores, valued for their high yield potential, uniform fruit size, and resistance to common tomato diseases such as Fusarium wilt and bacterial wilt. Fantastic F1 typically has medium to large fruits with a maturity period of 65–70 days after transplanting, while Diamante Dmax F1 is characterized by larger fruit size, firmer flesh, and a longer shelf life, making it suitable for fresh market and transport.

A common approach to address seed germination issues is the practice of seed enhancements such as priming. Priming, a process of initiating metabolic activity in the seeds by wetting but keeping germination process at bay, dates back to the time of Theophrastus (Raj and Raj 2019). Seed priming can be a technological tool to provide excellent seedling performance in the field, thereby promote sustainable crop production (Leubner, 2000). Seed enhancement such as priming is a pre-sowing seed treatment that allows controlled hydration of seeds to imbibe water or other substances and go through the first stage of germination but does not allow radicle protrusion (Copeland and McDonald 2000). In general, priming point to enhance germination of various crops. Studies have shown that priming has been successful for such crops as pepper, carrot, onion, corn (Bradford et al. 1990), celery, parsley (Pill 1986), wheat, barley, sorghum and ryegrass (Danneberger et al. 1992). Indeed, priming has become a common agricultural practice among farmers in India, Nepal, Pakistan, Botswana, Malawi and Zimbabwe. With improved seedling germination and emergence, yields from 22-50% for crops such as chickpea, maize, wheat, sorghum and upland rice in the semi-arid region (Raj and Raj 2020).

As research advances, seed priming research has extended to wider procedures beyond water alone, hence a more inclusive term, seed enhancement. Seed enhancement includes methodologies such as halopriming, osmopriming or osmoconditioning, solid matrix priming, hormonal priming, biopriming (Raj and Raj 2020), chemical priming, physical priming (Seth 2023) and bio-stimulant priming (Masundo et al. 2018). Bio-stimulants are extracts from natural materials that contain bioactive substances which augment plant tolerance to abiotic and biotic stresses and improve crop quality and production by promoting physiological processes in the plant (Bulgari et al. 2014). Irradiated carrageenan biostimulant (ICB) contains degraded polysaccharides that act as elicitors of plant growth, enhancing physiological processes such as cell division, enzyme activation, and nutrient uptake (Hossain and Shourove 2022). The sulfate groups in carrageenan can stimulate antioxidant enzyme activity and osmolyte accumulation, improving stress tolerance during germination. Additionally, ICB may enhance hormonal balance, particularly increasing gibberellic acid activity, which promotes faster radicle emergence and seedling establishment.

Development and evaluation of seed enhancement methods are commonly conducted initially through germination and seedling development assays. The value of germination characteristics cannot be overstated. It is the initial crucial process that influences crop yield and quality (Tuan et al. 2019). Thus, quality seed is among the primary requirements of a successful agriculture undertaking where each and every seed should easily germinate and produce vigorous seedlings (Komala et al. 2018). The International Seed Testing Association (2015) has recommended procedures and observation points for technical seed quality assays. The present study aims to determine and compare the seed enhancement effects and potential of water-based and irradiated carrageenan-based treatments on commercial tomato F1 hybrids seeds, following the standards and observation indicators of ISTA.

MATERIALS AND METHODS

Tomato genotypes and seed treatments

Two commercial F1 hybrid tomato varieties, Fantastic-F1™ (Fantastic) and Diamante Max-F1™ (Diamante Max) were obtained from local seed agri-supply retailers. The two seedlots were subjected to different seed enhancement serving as experimental treatments. The treatments were as follows: Untreated (T_1, Control), Hydro-priming (T_2, seeds were soaked in distilled water alone), 1% ICB (T_3, prepared by diluting a commercial formulation of irradiated carrageenan biostimulant, Vitalgro Plant Growth Promoter™ in distilled water at 1 mL L^{-1} (v/v)), 2% ICB (T_4 , 2 mL L^{-1}), 3% ICB (T_5, 3 mL L^{-1}) and Hydroconditioning (T_6- done by suspending seeds inside an enclosed container filled with water to achieve high relative humidity or 100% RH, 48 hr before sowing to partially hydrate seeds).

Seed soaking treatment and germination set-up

For T2, T3, T4 and T5, the following procedures were conducted: a total of 500 seeds per treatment per variety were placed inside a clean cheese cloth bag and completely submerged into different aforementioned treatments for 2 hr. After soaking, seeds were air dried at room condition (25-27°C) for 24 hr. Air-dried lots along with T1 and T6 seeds were sown in Petri dishes lined with moist filter paper. The germination set up was placed under room temperature (average daily temperature of 25-27°C) with alternating light regime, 12 hr light / 12 hr dark exposure using a 50 watts fluorescent light for 14 days. For the seedling emergence test, seeds were sown on a potting mix composed of an equal part of cocopeat, carbonized rice hull and garden soil. Experimental setup was laid out in 2-factor Completely Randomized Design with 5 replications. For every replicate, 15 seeds were sown per petri dish. The design allowed for testing of main effects and interactions between variety and seed enhancement treatment. However, statistical analysis revealed no significant interaction effects between the two factors for the parameters measured; hence, only main effects are presented.

Sampling and data recording

Ten seeds per replicate per treatment were randomly selected for the measurement of germination percentage, germination index, seedling vigor index I and II, seedling emergence and seedling fresh and dry weight. Data recording and calculations are as follows:

Germination percentage (GP). This was evaluated following the ISTA (2015) prescribed procedure for germination of tomato seeds.

Germination index, (GI). This was measured by counting the seedlings with 2 mm radicle protrusion starting at day 1 (first count) until day 14 (final count). GI was computed as follows:

$$GI = \frac{no.of\ normal\ seedlings}{day\ of\ first\ count} \ldots + \frac{no.of\ normal\ seedlings}{day\ of\ last\ count}$$

Seedling Vigor Index – I, (SVI-I). This was done by getting the average length of 10 normal seedlings and multiplied by the germination percentage. Seedling length was comprised of seedling's root and shoot length measured using a ruler.

$$SVI - I\ = germination\ x\ seedling\ length\ (cm)$$

Seedling Vigor Index – II, (SVI-II). This was done by getting the dry weight of 10 normal seedlings then multiplied by the germination percentage.

$$SVI - II\ = germination\ x\ seedling\ dry\ weight\ (g$$

Seedling Emergence (SE). Control and treated seeds were sown in a seed box filled with a potting mix (ordinary garden soil and carbonized rice hull, CRH). Each treatment was replicated 3 times and with 15 seeds per replicate. Counting of germinated seedlings was done 14 days after sowing. Seedlings

Table 1. Effects of seed enhancement treatments on germination and seedling variables on hybrid tomato variety, Fantastic F1

Seed quality parameters							
Treatments	**Germination (%)**	**Germination index**	**Seedling vigor index- I**	**Seedling vigor index- II**	**Seedling emergence (%)**	**Seedling fresh weight (g)**	**Seedling dry weight (g)**
T_1- Control (no soaking)	65.33 ^{a}	1.52 ^{a}	329.80 ^{b}	7.84 ^{d}	80.00 ^{b}	1.22 ^{d}	0.12 ^{d}
T_2- Hydro-priming	72.00 ^{a}	1.85 ^{a}	433.15 ^{b}	10.08 ^{c}	50.00 ^{e}	1.26 ^{c}	0.14 ^{c}
T_3- 1 % ICB	73.33 ^{a}	1.92 ^{a}	565.84 ^{a}	13.93 ^{a}	85.00 ^{a}	1.39 ^{a}	0.19 ^{a}
T_4- 2 % ICB	69.33 ^{a}	1.92 ^{a}	371.35 ^{b}	10.40 ^{b}	70.00 ^{d}	1.30 ^{b}	0.15 ^{b}
T_5- 3 % ICB	70.67 ^{a}	1.85 ^{a}	355.03 ^{b}	6.36 ^{f}	75.00 ^{c}	1.09 ^{f}	0.09 ^{f}
T_6- Seed conditioning	69.33 ^{a}	1.84 ^{a}	345.27 ^{b}	7.63 ^{e}	80.00 ^{b}	1.17 ^{e}	0.11 ^{e}
SD	13.13	0.35	57.97	1.73	11.87	0.12	0.11
***P*- value**	0.9497	0.4945	<.0001	<.0001	<.0001	<.0001	<.0001
CV (%)	18.76	19.2	14.49	18.41	16.18	9.12	12.4

Means followed by the same letter within a column are not significant at 5% level (Tukey's HSD test). ICB-Irradiated carrageenan biostimulant. Values are presented as mean ± standard deviation (SD), and corresponding P-values for treatment effects are indicated.

that emergence above the soil line were considered germinated. SE was computed as follows:

$$SE = \frac{no. of\ normal\ seedlings\ above\ soil\ line}{total\ no. of\ seeds\ used}\ x\ 100$$

Seedling Fresh weight (SFW). This was obtained by getting the average weight (g) of 10 seedlings per replicate using analytical balance on the 14th day after sowing.

Seedling Dry weight (SDW). This was obtained by oven-drying 10 seedlings per replicate at 70°C for 72 hr. Samples were weighed using analytical balance.

Data processing, analyses and visualization
Data were summarized in pc spreadsheet and analyzed by analysis of variance procedure using SAS On Demand for Academics (SAS Institute Inc., 2014) to determine significant differences in treatment means. The differences among means were compared using Tukey's Honest Significant Difference at 5% level of significance. Mean differences were also visualized using charting function in a pc spreadsheet application.

RESULTS AND DISCUSSION

Response of tomato hybrid variety, Fantastic F1
Germination responses of Fantastic to different seed enhancement treatments is summarized in Table 1. By and large, Fantastic F1 reacted differentially across treatments as measured in different germination and seedling parameters. Significant differences of treatment effects were noted in seedling vigor index 1, seedling vigor index 2, seedling emergence, seedling fresh weight and seedling dry weight. Percent germination and germination index however were not found to statistically differ among seed enhancement treatments applied. Of the statistically different effects, 1% ICB showed the maximum seedling vigor index 1 value at 565.84 which differed by 132.69 compared to the 2nd highest treatment value, water. The rest of the treatments did not differ from other but differed in value by as much as 103.35 (water vs. untreated). Seedling vigor index 2, seedling emergence and seedling weights showed more variations in the effects of each treatment. Treatment 1% ICB showed the maximum favorable values in all parameters across seed enhancement treatments. However, reaction of Fantastic seeds varied with all other treatments for the rest of the parameters. Lowest seedling vigor 2 value was recorded on 3% ICB while lowest seedling emergence was recorded on hydro-priming treatment. Interestingly, control and seed conditioning resulted to statistically tied values with 80% values even higher than those for 2% ICB and 3% ICB. On the other hand, seedling weights were lowest on 3% ICB with control, hydro-priming and hydro-conditioning having higher values than the former. Treatment, 2% ICB followed 1% ICB but was statistically lower. Additionally, seedling emergence across treatments were mostly higher than germination. Procedures for the two variables differ on substrate used, indicating possible substrate effects on seed germination of Fanta. Rekani et al (2016) noted that germination and seeding parameters of capsicum seeds vary with substrate used where soil, carbonized rice hull and peatmoss mixture gave the best values.

On the other hand, Fantastic also showed higher seedling dry weight values in most treatments except 1% ICB compared to Diamante Max suggesting varietal differences. Among the treatments, clear pattern of effects is obscured by observations on untreated, 3% ICB and conditioning. Nonetheless, seedling dry weight on aged seeds was shown to improve by seed priming treatments such as sunflower (Catiempo et al 2021, Kaya et al. 2024) and field beans (Amanpour-Balaneji and Sedghi (2012). Akbar et al. (2021) likewise noted that application of irradiated carrageenan as seed priming treatment not only accelerates the seed quality parameters but also enhances the seedling vigor as manifested by long shoot and root and an increased seedling biomass. They attributed the enhanced seedling fresh and dry weights may be due to increased cell division within the apical meristem of seedling roots, which might have caused the increase in seedling growth. The present observation may also hint of better varietal response of Fantastic to seed enhancements at its given initial seed quality. However, experimental

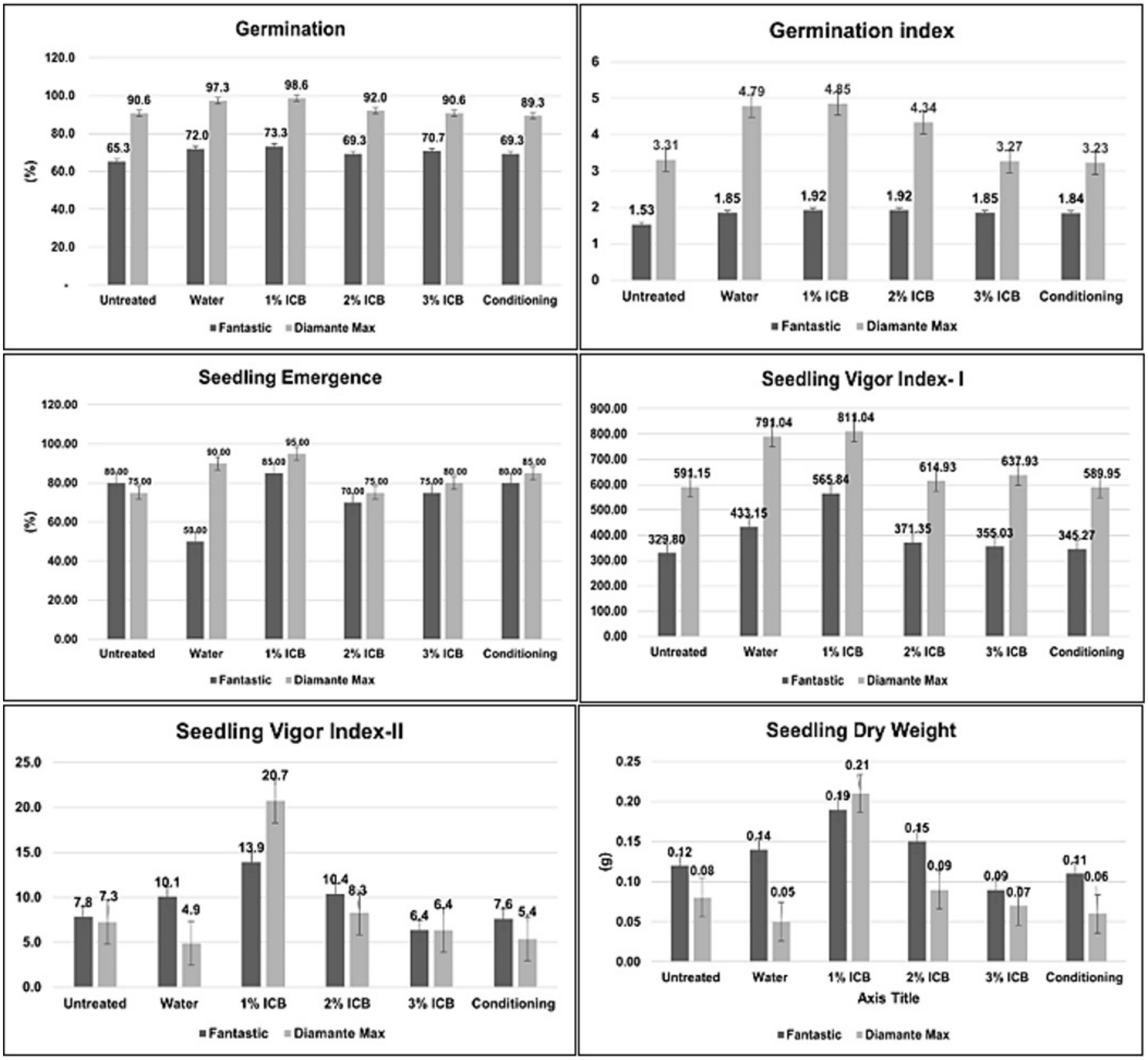


Figure 1. Graphical presentation of the values of seedling and germination parameters observed for Fantastic and Diamante Max across experimental treatments

limitations such as limited variety and/or seedlot quality factor confines the validity of the observations. Figure 1 visualizes the comparative responses of Fantastic and Diamante Max to different seed enhancement.

Response of tomato hybrid variety, Diamante Max F1

Table 2 summarizes the results for the variety, Dmax. In general, Dmax showed variable reaction to different seed enhancement treatment as measured by different germination and seedling parameters. The 1% ICB treatment resulted to the highest observed values across all parameters. Although the differences were not significant to hydro-priming in relation to germination and germination index. Seed conditioning showed the lowest values in four of the seven parameters measured. However, for germination and germination index with hydro-priming treatment, though values were slightly lower than 1% ICB, differences were not significant. Moreover, seedling vigor 2 and seedling emergence under hydro-priming treatment had the 2nd largest values after the 1% ICB. Differences however were statistically significant.

Effects of irradiated carrageenan biostimulant

The two F1 variety seedlots have way different base viability condition. Fantastic had 65.3% average germination while Diamante Max had 90.6%. Nonetheless observations showed effects of treatments across different parameters were distinct and significant. Data comparison between the best treatment (1% ICB) and untreated seeds for the observed parameters is summarized in Table 3 and illustrated in Figure 2. Based on best and lowest observed treatment values, Fantastic increased germination by 12.25% compared to 8.8% in Diamante Max. Germination index was increased by 25.49% in Fantastic and 44.27% in Diamante Max.

Table 2. Effects of seed enhancement treatments on germination and seedling variables on hybrid tomato variety, Diamante Max F1

Seed quality parameters							
Treatments	**Germination (%)**	**Germination index**	**Seedling vigor index- I**	**Seedling vigor index- II**	**Seedling emergence (%)**	**Seedling fresh weight (g)**	**Seedling dry weight (g)**
T_1- Control (no soaking)	90.62 ^{ab}	3.31 ^{bc}	591.15 ^{b}	7.25 ^{c}	75.00 ^{e}	1.21 ^{c}	0.08 ^{b}
T_2- Hydro-priming	97.33 ^{a}	4.79 ^{a}	791.04 ^{ab}	4.87 ^{f}	90.00 ^{b}	1.09 ^{e}	0.05 ^{c}
T_3- 1 % ICB	98.66 ^{a}	4.85 ^{a}	811.04 ^{a}	20.72 ^{a}	95.00 ^{a}	1.43 ^{a}	0.21 ^{a}
T_4- 2 % ICB	92.00 ^{ab}	4.34 ^{bc}	614.93 ^{b}	8.28 ^{b}	75.00 ^{e}	1.23 ^{b}	0.09 ^{b}
T_5- 3 % ICB	90.61 ^{ab}	3.27 ^{bc}	637.93 ^{ab}	6.35 ^{d}	80.00 ^{d}	1.20 ^{d}	0.07 ^{b}
T_6- Seed conditioning	89.33 ^{ab}	3.23 ^{c}	589.95 ^{b}	5.36 ^{e}	85.00 ^{c}	1.01 ^{f}	0.06 ^{c}
SD	4.97	0.6	107.36	0.67	7.65	0.11	0.01
P-value	0.0051	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
CV (%)	5.34	15.01	15.96	7.64	9.18	9.04	7.71

Means followed by the same letter within a column are not significant at 5% level (Tukey's HSD test). ICB-Irradiated carrageenan biostimulant. Values are presented as mean ± standard deviation (SD), and corresponding P-values for treatment effects are indicated.

Table 3. Percent difference in values of between 1% ICB and untreated seeds across germination and seedling parameters observed.

Parameter	**Variety**	
	Diamante Max	**Fantastic**
Germination (%)	8.8	12.25
Germination Index	44.27	25.49
Seedling Emergence (%)	26.67	6.25
Seedling vigor 1	37.18	71.55
Seedling vigor 2	183.56***	78.20*
Seedling fresh weight (g)	27.27**	13.93*
Seedling dry weight (g)	10.00***	58.3*

Lowest value was observed on: *3% ICB, **Hydro-priming, ***Conditioning

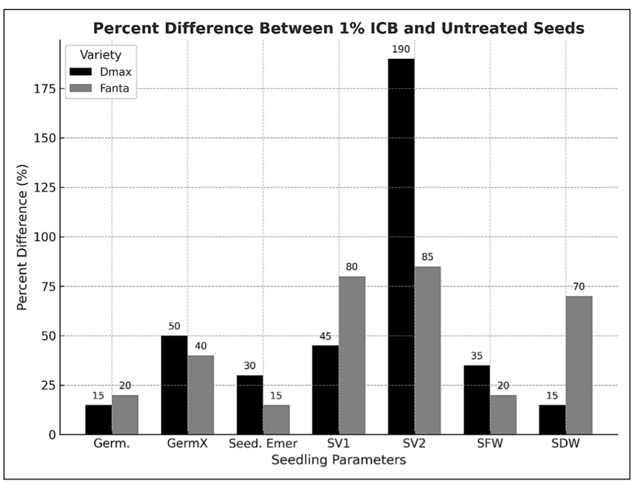


Figure 2. Percent difference in germination and seedling growth parameters between 1% ICB-treated and untreated seeds of two F1 varieties

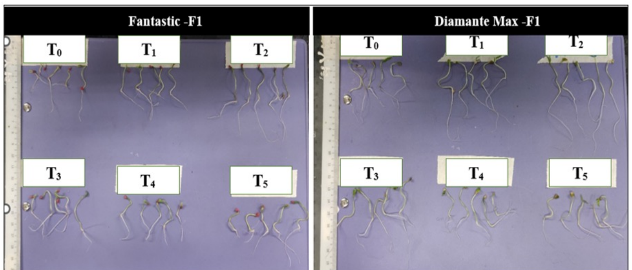
Seedling vigor index 1 was increased by 71.55% and 37.18% in Fantastic and Diamante Max, respectively. Seedling emergence increased by 26.67% in Diamante Max and 70% in Fantastic. In the latter however, water soaking treatment had the lowest seedling emergence among treatment. While the highest values for the rest of the parameters were consistently observed under 1% ICB, the lowest effects however were not always noted on untreated seeds. For Fantastic, lowest values for seedling vigor 2, seedling fresh weight and seedling dry weight were observed for 3% ICB. While for Diamante Max lowest values were recorded on hydro-priming and conditioning. Mamede et al (2023) further discussed that carrageenan treatment in seeds stimulates plant growth by enhancing basal metabolism, such as cell division, synthesis of purine and pyrimidine and the assimilation of nitrogen and sulfur. Mechanistically, irradiated carrageenan may enhance germination by modulating osmotic balance, stimulating antioxidant enzyme activities, and promoting cell division through the activation of phytohormone-like compounds present in degraded polysaccharides (Bulgari et al. 2014; Mamede et al. 2023). In addition, chemical characterization of irradiated carrageenan using Fourier-transform infrared spectroscopy (FTIR) and nuclear magnetic resonance (NMR) analyses has revealed structural modifications such as reduced molecular weight, changes in sulfate ester group distribution, and increased formation of biologically active oligosaccharides (Akbar and Ahmed, 2018; Hossain and Shourove, 2022). These structural changes are believed to facilitate improved water uptake by seeds, modulation of osmotic potential, and stabilization of cellular membranes during imbibition. Moreover, the sulfate groups and derived oligosaccharides can act as elicitors, triggering antioxidant defense systems and phytohormone-like activities that promote cell division and elongation (Bulgari et al. 2014; Hotta et al. 2016). Such biochemical mechanisms could explain the observed increases in seedling vigor and biomass in the present study, particularly at the optimized 1% ICB concentration.

Water-based enhancement effects on tomato hybrids seed

Table 4 presents the arithmetic comparison of water-based seed enhancement versus untreated seeds. In general, treated seeds have higher values for germination and seedling variables measured for both hybrids. However, hydro-priming had higher recorded values than seed conditioning for many parameters measured. Germination was higher by 14.29% on Fantastic and 7.39% on Diamante Max while germination index was 20.90% and 44.71% higher on Fantastic and Diamante Max, respectively. Seedling vigor 1 was 31.35% higher on Fantastic and 33.79% on Diamante Max. Differential effects on varieties,

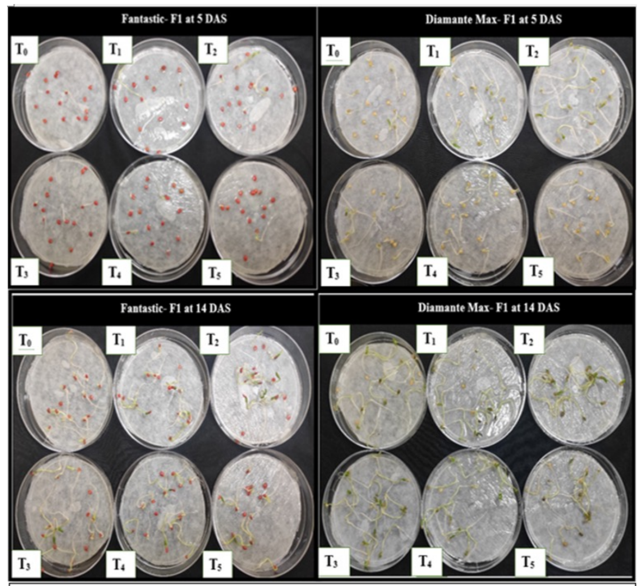
Table 4. Comparison of effects of hydropriming and conditioning to untreated seeds of tomato F1 hybrids, Fantastic and Diamante Max

Parameter	Variety		Parameter	Variety	
	Fantastic	Diamante Max		Fantastic	Diamante Max
Germination			**Seedling vigor 1**		
Hydropriming	14.29	7.39	Hydropriming	31.35	33.79
Hydroconditioning	5.67	-1.43	Hydroconditioning	4.7	-0.2
Germination Index			**Seedling vigor 2**		
Hydropriming	20.9	44.71	Hydropriming	29.49	-32.87
Hydroconditioning	20.26	2.24	Hydroconditioning	-2.56	-26.03
Seedling emergence			**Seedling dry weight**		
Hydropriming	-37.5	20	Hydropriming	16.67	-0.37
Hydroconditioning	0	13.33	Hydroconditioning	-8.33	-2.5



Representative seedlings of Fantastic-F1 (left) and Diamante Max-F1 (right) subjected to different treatments: **T0** – untreated, **T1** – water, **T2** – 1% ICB, **T3** – 2% ICB, **T4** – 3% ICB, and **T5** – conditioning.

Figure 3. Effect of ICB Treatments on Seed Germination and Seedling Growth of Fantastic-F1 and Diamante Max-F1



Seedlings of *Fantastic-F1* (left) and *Diamante Max-F1* (right) under six treatments: **T0** – untreated, **T1** – water, **T2** – 1% ICB, **T3** – 2% ICB, **T4** – 3% ICB, and **T5** – conditioning. Germination was evaluated at **5 DAS (first count)** and **14 DAS (final count)** following ISTA rules.

Figure 4. Germination response of Fantastic-F1 and Diamante Max-F1 under different ICB treatments

however, were recorded on seedling emergence, seedling vigor 2 and seedling dry weight. Diamante Max had 20% higher seedling emergence while Fantastic is 37.50% lower than untreated seeds. An opposite observation was recorded on seedling vigor 2 with Fantastic showing 29.49% higher value than untreated whereas Diamante Max was 32.87% lower. Fantastic had higher seedling dry weight by 16.67% compared to untreated seeds but Diamante Max is lower by a negligible 0.37%. The importance of seedling biomass quantification as measure of seedling growth and seed quality has been emphasized by Chen et al (2016).

Effects of hydro-priming and seed conditioning

These seed enhancement treatments practically use water as the conditioning material differing only in the process of treatment. Comparing the two water-based seed treatments with the untreated seeds, result showed in general, some degree of enhancement effects on germination and seedling variables compared to untreated seeds. While results also showed that hydro-priming works better than seed conditioning as it yielded larger difference with the untreated seeds in most variables observed for both F1 hybrid seedlots. The beneficial effects of seed priming with water have been well acknowledged and traces its origins in the works of early ancient Greeks observing seed germination behavior (Paparella et al. 2015). In wheat, Murungu (2011) reported that hydro-priming increased field emergence and shorter germination time. Narayan Rout et al (2024) reported that hydro-priming one-year old tomato seeds for 12 hr gave the best values for germination and seedling parameters. Ranmichai et al (2022) similarly reported that hydropriming Philippine commercial rice varieties improves germination and seedling vigor. Hydropriming in general has been considered a traditional cost-effective agricultural practice to improve seed germination and field emergence of crops such as tomato particularly when planted in saline soils (Seth, 2023). Present results conform with previous observations on the benefits and effects of hydro-priming on germination and seedling growth.

Results and observation showed that the Fantastic and Diamante Max seedlots vary in base viability which can be associated with the initial condition of the seeds at the point of acquisition. From its initial seed quality off the production and processing facilities seed quality can be maintained or affected until the distribution points. Among such factors affecting viability are crop production environment, production provenance, seed moisture content at packaging, packaging material and condition, storage condition. (TNAU, 2024; Choudhury and Bordolui, 2023). Additionally, inherent genetic makeup of the variety or crop species also influence viability and longevity (TNAU, 2024). Hence, while seedlot qualities are tested at processing points, germination and viability of commercial seedlots, such as that of tomato, maybe influenced by store shop conditions and shop age of seed lots at the points of sale. At the point of acquisition, Diamante Max was tested at 85% germination and Fantastic was tested 78%. Moreover, Fantastic "best before date" is 1 year ahead of Diamante Max. The base germination profile thus validated its lower values observed (data not shown) and the varietal differences in germination response are further shown in Figure 4.

Thus, to improve off-shelf seed quality and maximize cost of seed, one approach is subjecting the seeds to priming and enhancement treatments. In this study, it was shown that both off-shelf hybrid tomato seedlots responded to different seed priming treatments. But for both varieties, maximum values for traits observed was recorded on 1% ICB treatment. Effects of carrageenan in plant growth have been studied. In peanut, Abad et al (2018) found that germination was shortened by 5-11 days using an irradiated carrageenan-based treatment at 40-60ppm. Similarly, Hossain and Shourove (2022) summarized the positive effects of carrageenan on seed germination. In turnip seeds, Mamede et al (2023) found that percent germination and seedling growth were best obtained in seeds treated with carrageenan extract. In durum wheat, carrageenan-based seed coating was found to improved seed germination particularly on drought conditions (Hotta et al. 2016). Dutta et al (2019) reported to improve germination on solanaceous seeds treated with carrageenan solution. The current results similarly found the improvement effect of carrageenan seed treatment on germination and seedling parameters of hybrid tomato where maximum values obtained at 1% ICB treatment. Mamede et al (2023) further discussed that carrageenan treatment in seeds stimulates plant growth by enhancing basal metabolism, such as cell division, synthesis of purine and pyrimidine and the assimilation of nitrogen and sulfur. Hence, this may relate to the generally higher seedling weights observed. However, a weak trend was noted that as ICB dose increases parameter values tend to be lower (Figure 3). For instance, 2% ICB had lower recorded value than 1% ICB and more so with 3% ICB. In peanut, Abad et al (2018) noted that yield was not influenced by increasing the dose of irradiated carrageenan treatment. Further they noted that shortening of germination time was not improved at higher carrageenan concentration.

CONCLUSION AND RECOMMENDATIONS

The results thus showed that commercial grade irradiated carrageenan-based solution applied as seed enhancement treatment for hybrid F1 tomato seeds yield comparatively better responses in seedling and germination indicators, than water-based seed treatments. In particular, 1% ICB yields the best responses for both seedlots which ranged from 12.25% to 72.80% for Fantastic and 8.80% to 183.56% for Diamante Max, compared to untreated seeds. However, increasing dose did not clearly result to increasing effects beyond the 2% solution. Additionally, water-based treatments also yield favorable results with hydropriming having higher values than hydroconditioning. From the results, development of optimized and standardized dilution and application protocol using commercial grade irradiated carrageenan for farm-level application can be a helpful intervention for tomato growers to maximize seed inputs and improve crop stand. Moreover, such forward R and D may be designed to include other crops species as well.

On the other hand, some observations also faintly suggest that varietal differences and/or or seed quality status may yield differential reaction. Hence, the following are forwarded as recommendations: germination and viability assay of seedlots with differential base seed quality characteristics; seed quality assay using differential genotypes and substrates interaction effects assays.

ACKNOWLEDGMENT

The authors wish to thank the Accelerated Science and Technology Human Resource Development Program (ASTHRDP) of the Department of Science and Technology-Science Education Institute (DOST-SEI) for the financial support and the Institute of Crop Science, College of Agriculture and Food Science, UPLB for providing the facility throughout the course of this work.

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