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Effect of titanium dioxide and zinc oxide nanoparticles on germination and vigour in tomato (*Solanum lycopersicum* L.) seeds

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Abstract
The present investigation was carried out to assess the effect of titanium dioxide and zinc oxide nanoparticles on germination and vigour in tomato (*Solanum lycopersicumI* L.) seeds in the Seed Testing Laboratory of the Department of Genetics and Plant Breeding, Sam Higginbottom University of Agriculture, Technology & Sciences, Allahabad during 2017-18. These five varieties (Kashi Amarit (DVRT-1), Kashi Anupame (DVRT-2), Kashi Adarsh, Kashi Vishesh (H-86), Kashi Aman) are conducted in CRBD having four replications treated with distilled water @ 100ml., control, Nano priming - TiO_2 (25 mg), TiO_2 (50 mg), TiO_2 (75 mg), TiO_2 (100mg), TiO_2 (150 mg), TiO_2 (200 mg), ZnO (25mg), ZnO (50mg), ZnO (75 mg), ZnO (100mg), ZnO (150mg), ZnO(200 mg) at a period interval of 6 hours respectively. In all the five varieties TiO_2 25 mg and ZnO 25 mg was found as best among all the concentrations for seed quality parameters and vigour parameters *viz.* in germination percentage Kashi Aman found superior (83.56 %) at TiO_2 25 mg while Kashi Amarit (90.00 %) at ZnO 25 mg. In speed of germination Kashi Anupame found superior (27.50) at TiO_2 25 mg while Kashi Amarit found superior (28.68) at ZnO 25 mg. In mean germination time Kashi Amarit found superior (43.87) at TiO_2 25 mg and (43.31) at ZnO 25 mg. In root length Kashi Amarit found superior (10.04 cm) at TiO_2 25 mg and (8.77 cm) at ZnO 25 mg. In shoot length Kashi Amarit found superior (5.56 cm) at TiO_2 25 mg while Kashi Aman (5.403 cm) at ZnO 25 mg. In seedling length Kashi Amarit found superior (15.43 cm) at TiO_2 25 mg and (15.03 cm) at ZnO 25 mg. In seedling fresh weight Kashi Amarit found superior (2.03 g) at TiO_2 25 mg and Kashi Adarsh (2.05 g) at ZnO 25 mg. In seedling dry weight Kashi Anupame found superior (0.027 mg) at TiO_2 25 mg and (0.027mg) at ZnO 25 mg. In vigour index –I Kashi Amarit found superior (1062.50) at Tio_2 25 mg and (1087.50) at ZnO 25 mg. In vigour index –II Kashi Adarsh found superior (9.74) at TiO_2 25 mg and (9.59) at ZnO 25 mg. In electrical conductivity of seed leachate Kashi Vishesh found superior (68.66) at TiO_2 25 mg and Kashi Adarsh (69.13) at ZnO 25 mg. In seed metabolic efficiency Kashi Aman found superior (0.115) at TiO_2 25 mg and Kashi Amarit (0.115) at ZnO 25 mg. In field emergence index Kashi Vishesh found superior (94.40) at TiO_2 25 mg and (94.12) at ZnO 25 mg. The variance revealed considerable variability among the genotypes for all the characters. Titanium Dioxide (TiO_2) and Zinc Oxide (ZnO) nanoparticles at 25 mg concentration is beneficial to improve the seed quality and vigour parameters of tomato seeds.

Keywords: Nanopriming, nanoparticles, seed quality, seed vigour, germination, tomato, TiO_2, ZnO, titanium dioxide, zinc oxide

1. Introduction

Tomato (*Solanum lycopersicum* L.) is an important vegetable crop and has a significant role in human nutrition in human diet (Fekadu *et al.*, 2004) and belonging to the Solanaceae family, its origin is the Andean zone particularly Peru-Ecuador-Bolivian areas but cultivated tomato originated in Mexico. The Spanish introduced the tomato into Europe in the early 16th century and the mid-16th century tomatoes have been cultivated and consumed in southern Europe, though they only became widespread in north-western Europe by the end of the 18th century (Harvey *et al.*, 2002).

In the 17th century, Europeans took the tomato to China, south and south-east Asia and in the 18th century to Japan and the USA. It is most important and remunerative vegetable crop in India. Uttar Pradesh, Maharastra, Karnataka, Bihar and Orissa are major tomato-growing states in India. It is a warm-season vegetable, is grown extensively in cool season also. The optimum temperature required for its cultivation is 15^0 - 27^0 C.Tomato is grown in varied types of soil-sandy loam to clay, black soil and red soil- having proper drainage. The pH of the soil should be 7-8.5.Tomato can tolerate moderate acidic and saline soils.

In red and black soils of Karnataka, Maharastra and Madhya Pradesh, tomato hybrids are cultivated commercially. In World, the production and productivity of tomato is 160850.683 tonnes/ha. and 33.7tonnes/hectare respectivley in the area of 4778.406 hectare. Leading countries are china,Turkey, Italy, India, USA, Iran, Brazil, Spain etc (India position in world agriculture 2015). In India, crop was grown in an area of 36,000 hectare, During 1960 and present area 801‘000 ha and production in the country is 22337‘000 MT. and productivity is 20.6 tonnes/hectare. Leading producing states are Andhra pradesh, Gujarat, Madhya Pradesh, Chattisgarh, Uttar Pradesh,Karnataka, Maharastra, Haryana, Punjab and Bihar (Agricoop.gov.in 2017-18). It is one of the most popular salad vegetable and it is taken with great relish.Tomato has a significant role in human nutrition because of its rich source of lycopene, minerals and vitamins such as ascorbic acid and β-carotene which are anti-oxidants and promote good health. It is widely employed in cannery and made into soups, conserves, pickles. Ketchup, sauces, juices etc. Tomato juice has become an exceedingly popular appetizer and beverage. The well ripe tomato (per 100 g of edible portion) contains water (94.1%), energy (23 calories), calcium (1.0 g). Magnesium (7.0 mg), vitamin A (1000 IU), ascorbic acid (22 mg), thiamin (0.09mg), riboflavin (0.03 mg) and niacin (0.8 mg) (Uddain *et al.,* 2009). A rich source of minerals, vitamins and organic acids, tomato fruit provides 3-4% total sugar, 4-7% total solids, 15-30 mg/100g ascorbic acid, 7.5-10 mg/100ml titratable acidity and 20-50mg/100g fruit weight of lycopene.Nanoparticles are particles between 1 and 100 nanometres (nm) in size with a surrounding interfacial layer. The interfacial layer is an integral part of nanoscale matter, fundamentally affecting all of its properties. The interfacial layer typically consists of ions, inorganic and organic molecules.Application of nanomaterials in vegetables improved seed germination and seedling vigour by enhancing α- amylase activity, resulting in higher soluble sugar content for supporting seedlings growth. Furthermore, they stimulate the up-regulation of aquaporin genes in germinating seeds. Also nanoparticles through nanopriming creates nanopores for enhanced water uptake, rebooting antioxidant system in seeds, generation of hydroxyl radicals for cell wall loosening and nanocatalyst for fastening starch hydrolysis.Seed priming is a pre-sowing seed treatment that involves the controlled hydration of seeds, sufficient to allow pre-germinative metabolic events to take place, but radical emergence does not occur**.** Priming allows the metabolic processes necessary for germination without protrusion of radicle. Priming is an enhancement method that accelerates germination and emergence**.** Increased germination rate and uniformity have been attained due to metabolic repair during imbibitions.Seed priming is a commercially used technique for improving seed germination and vigour. It involves imbibitions of seeds in water under controlled conditions up to the point of radical emergence followed by drying the seed back to the initial moisture content of the seeds (McDonald, 2000). This treatment induces rapid, uniform and increased germination, improved seedling emergence, vigour and growth under diverse environmental conditions resulting in better stand establishment and the alleviation of phyotochrome-induced dormancy in some crops (Varier *et al.,* 2010). Seed Vigour, is frequently used as a measure of seed quality by Agronomists, Seed Analysts and related Scientists, as well as by some progressive farmers. For practical purposes, defined seed vigour as “the sum of all seed attributes, which favour rapid and uniform stand establishment in the field“. Until fairly recently, it was generally assumed that the influence of seed vigour on performance didnot extend beyond emergence. But now, it seems quite clear that the vigour of seed can influence the growth, development and productivity of the plants produced**.**Today it has become important to increase crop production to feed the growing world population. To meet this increasing demand, researchers are trying to develop an efficient and ecofriendly production technology based on the innovative techniques to increase seedling vigour and plant establishment through physical seed treatments. In regard nano technology has come up with certain techiniques and products which will help to improve the seed quality parameters. Certain elements still failed to get recognition as an essential nutrient for plant growth and development. Plants, under certain conditions, were reported to be capable of producing natural mineralized nano-materials (NMs) necessary to their growth.The recent advances in nanotechnology and its use in the field of agriculture are astonishingly increasing; therefore, it is tempting to understand the role of Nano Titanium dioxide (n-TiO_2), Zinc Oxide in the germination,vigour and seedling characters of tomato seeds.

2.Materials and Method

The experiment was carried out in the Post Graduate Laboratory, Department of Genetics and Plant Breeding, Naini Agricultural Institute, Sam Higginbottom University of Agriculture Technology and Sciences, Allahabad during the year 2017-18.Seeds of tomato used in the experiment were collected from IIVR,Varanasi. Collected seed samples were stored at 20^0 C.

2.1 Experimental Materials

Tomato seeds (Varieties), Titanium dioxide nano particles (TiO_2), Zinc oxide nanoparticles (ZnO), Sodium Lauryl Sulphate (SLS), Sodium hypo-chlorite,Petri dish,Germination paper,Germination chamber, Electrical conductivity Meter, Electrical Weighing Balance, Measuring scale, Hot air oven, Autoclave, Ultra Sonicator, Distilled water.

2.2 List of Varieties

Kashi Amarit(DVRT-1),Kashi Anupame(DVRT-2),Kashi Adarsh,Kashi Vishesh(H-86),Kashi Aman

2.3 Methodology

Method for preparation of Titanium dioxide (TiO_2) and Zinc oxide (ZnO) nanoparticles

Nanoparticle 1(Titanium dioxide): Chemicals (TiO_2 and SLS) are weighed in equal proportion and poured into individual glass beakers treatment wise i.e T_1 = TiO_2 25mg + SLS 25mg, T_2 = TiO_2 50mg + SLS 50mg, T_3 = TiO_2 75mg + SLS 75mg, T_4 = TiO_2 100mg + SLS 100mg, T_5 = TiO_2 150mg + SLS 150mg, T_6 = TiO_2 200mg + SLS 200mg. 100ml of distilled water was added to each beaker. The beakers were kept in the ultra sonicator for 30 minutes. After sonication the nanoparticles get dispersed and white milky solution was formed.

Tomato seed treatment: Collected seed samples were sterilized with 1% Sodium hypochlorite.

Prepared solution was poured into petriplates treatment wise. Hundred seeds of each tomato variety were kept in petriplate of each treatment concentration for six hours in the laboratory. After six hours seeds were placed on moistened blotter paper and dried for some time. Petriplates were taken and wet germination paper was placed in it. Seeds of each variety are sown at a rate of 25 seeds per petriplate treatment wise in four replications and are covered with a layer of another wet germination paper.Then the petriplates were kept in germination chamber for 14 days(till final count) and all the seedling parameters were recorded.

Nanoparticle 2(Zinc oxide): Chemicals(ZnO and SLS) are weighed in equal proportion and poured into individual glass beakers treatment wise i.e T_7 = ZnO 25mg + SLS 25mg, T_8 = ZnO 50mg + SLS 50mg, T_9 = ZnO 75mg + SLS 75mg, T_{10} = ZnO 100mg + SLS 100mg, T_{11} = ZnO 150mg + SLS 150mg, T_{12} = ZnO 200mg + SLS 200mg. 100ml of distilled water was added to each beaker.The beakers were kept in the ultra sonicator for 30 minutes.After sonication the nanoparticles get dispersed and a white milky solution was formed.

Tomato seed treatment: Collected seed samples were sterilized with 1% Sodium hypochlorite.
Prepared solution was poured into petriplates treatment wise. Hundred seeds of each tomato variety were kept in petriplate of each treatment concentration for six hours in the laboratory. After six hours seeds were placed on moistened blotter paper and dried for some time. Petriplates were taken and wet germination paper was placed in it. Seeds of each variety are sown at a rate of 25 seeds per petriplate treatment wise in four replications and are covered with a layer of another wet germination paper. Then the petri plates were kept in germination chamber for 14 days(till final count) and all the seedling parameters were recorded.
Along with these one control (T_0) was also taken i.e 100 untreated seeds of each variety were primed in distilled water for 6 hours and sown at a rate of 25 seeds per petriplate in four replications. The petriplates were further placed in germination chamber for 14 days. All the results of treated seeds were compared with the control.

2.4 Lay out of Experiment
The gross plot size 74.34 m^2 was divided into four sub-plots. The sub-plots were used to replicate the treatments of four each sub-plots which was divided into 5 units of equal dimension and with a spacing of 12.3 × 1.5 cm^2.

2.5 Observations Recorded
Germination percent (ISTA, 2001), Speed of germination (days $^{-1}$), Mean germination time, Root length (cm), Shoot length (cm), Seedling length (cm), Seedling fresh weight (g), Seedling dry weight (mg), Vigour Index – I, Vigour Index – II, Electrical conductivity of seed leachates (mhos/cm/seed), Seed Metabolic Efficiency, Field Emergence Index.

2.6 Statistical Analysis
The data recorded was analyzed using formula of CRD and RBD. Comparison of mean were done by utilizing least significance difference(LSD) at 5% level.

Plate 1: Dissolving Nanoparticles in distilled water and kept in Ultra Sonicator

Plate 2: Nano particle solution after Ultra Sonication

3. Results and Discussion
3.1 Germination Percentage
(A) Kashi Amarit: Data in table 2 exhibits a significant variation in germination of tomato. It is evident from the table that significantly maximum increase in germination percentage occurs by T_7 (90.00 %) followed by T_1 (84.00 %), T_{11} (83.50%) while lowest germination (76.50 %) was observed with unprimed control.

(B) Kashi Anupame: Data in table 3 exhibits a significant variation in germination of tomato. It is evident from the table that significantly maximum increase in germination percentage occurs by T_7 (88.23 %) followed by T_8 (86.03 %), T_2 (82.47%) while lowest germination (77.28 %) was observed with unprimed control.

(C) Kashi Adarsh: Data in table 4 exhibits a significant variation in germination of tomato. It is evident from the table that significantly maximum increase in germination percentage occurs by T_7 (87.68 %) followed by T_8 (86.58 %), T_1 (82.39%) while lowest germination (77.49 %) was observed with unprimed control.

(D) Kashi Vishesh: Data in table 5 exhibits a significant variation in germination of tomato. It is evident from the table that significantly maximum increase in germination percentage occurs by T_7 (89.34 %) followed by T_8 (84.93 %), T_1 (83.23%) while lowest germination (76.87 %) was observed with unprimed control.

(E) Kashi Aman: Data in table 6 exhibits a significant variation in germination of tomato. It is evident from the table that significantly maximum increase in germination percentage occurs by T_7 (89.62 %) followed by T_8 (84.00 %), T_1 (83.56%) while lowest germination (77 %) was observed with unprimed control.

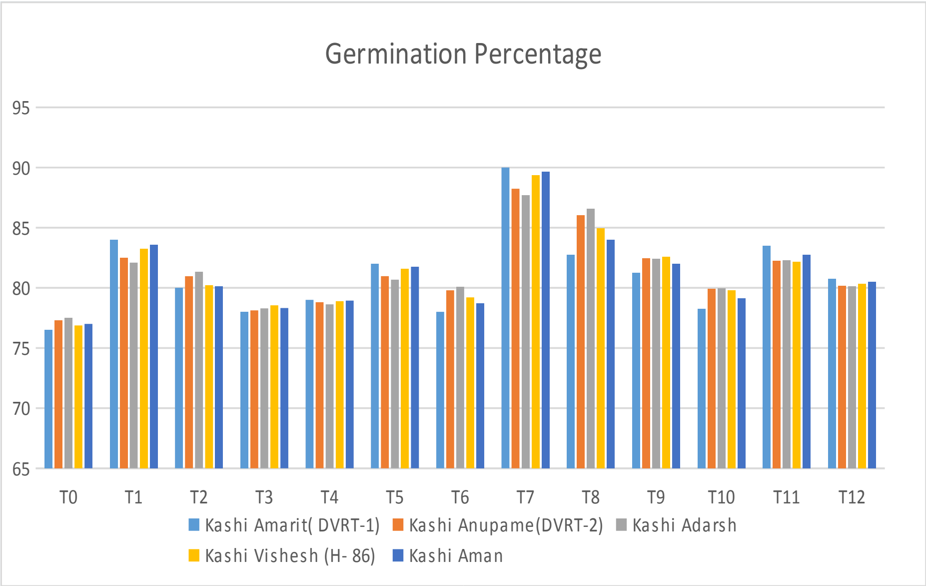

Fig 3.1(A): Histogram depicting performance of five varieties for Germination percentage

The seeds treated with nanoparticles (Titanium dioxide and Zinc oxide) at low concentrations showed highest germination percentage because aquaporins play important role in enhancing seed germination. They create nanopores which enhance water uptake, rebooting antioxidant system in seeds, generation of hydroxyl radicals for cell wall loosening, and nanocatalyst for fastening starch hydrolysis.NPs increase some enzymes such as nitrate reductase, superoxide dismutase, ascorbate peroxidase, guaiacol peroxidase and catalase activities and reduce H_2O_2 and superoxide radicals and promote the antioxidant system that can improve seed germination percentage.

Similar finding were also reported by Shah and Belozerova (2009), Moreno *et al.*, (2010), Kasra *et al.*, (2011) [39], Kasra Maroufi *et al.*, (2011) [39]., Hassan *et al.*, (2012), Karunakaran *et al.*, (2012).

Kasra *et al.*, (2011) [39] stated that the nano priming of green gram seeds with titanium dioxide nanoparticles could improve the germination percentage, seedling dry weight and seedling vigor when compared with control.

3.2 Speed of Germination

(A) Kashi Amarit - Data in table 2 exhibits a significant variation in speed of germination of tomato. It is evident from the table that significantly maximum increase in speed of germination occurs by T_7 (28.68) followed by T_8 (27.12), T_1 (26.31) while lowest speed of germination (18.06) was observed with T_{12}.

(B) Kashi Anupame: Data in table 3 exhibits a significant variation in speed of germination of tomato. It is evident from the table that significantly maximum increase in speed of germination occurs by T_7 (28.09) followed by T_1 (27.50), T_9 (26.87) while lowest speed of germination (17.96) was observed with T_{12}.

(C) Kashi Adarsh: Data in table 4 exhibits a significant variation in speed of germination of tomato. It is evident from the table that significantly maximum increase in speed of germination occurs by T_7 (27.94) followed by T_1 (26.63), T_8 (26.60) while lowest speed of germination (17.82) was observed with T_{12}.

(D) Kashi Vishesh: Data in table 5 exhibits a significant variation in speed of germination of tomato. It is evident from the table that significantly maximum increase in speed of germination occurs by T_7 (27.87) followed by T_8 (26.87), T_1 (25.62) while lowest speed of germination (18.00) was observed with T_{12}.

(E) Kashi Aman: Data in table 6 exhibits a significant variation in speed of germination of tomato. It is evident from the table that significantly maximum increase in speed of germination occurs by T_7 (27.18) followed by T_1 (26.06), T_9 (25.81) while lowest speed of germination (18.31) was observed with T_{12}.

The seeds treated with nanoparticles (Titanium dioxide and Zinc oxide) at low concentrations showed highest Speed of germination because of faster initiation of the metabolic activities with in the seed.Varieties that show high speed of germination directly indicates high vigour.

Similar finding were also reported by Azimi *et al.*, (2013), Feizi *et al.*, (2013), Habtamu Ashagre *et al.*, (2013). Azimi *et* *al.*, (2013) through their results revealed that the exposure of wheat grass seeds to the low doses of nano titanium dioxide particles could promote the germination percentage and also the germination rate could be faster when compared with bulk sized titanium dioxide particles and control treatments. Also there was increase in root, shoot, seedlings lengths and root biomass.

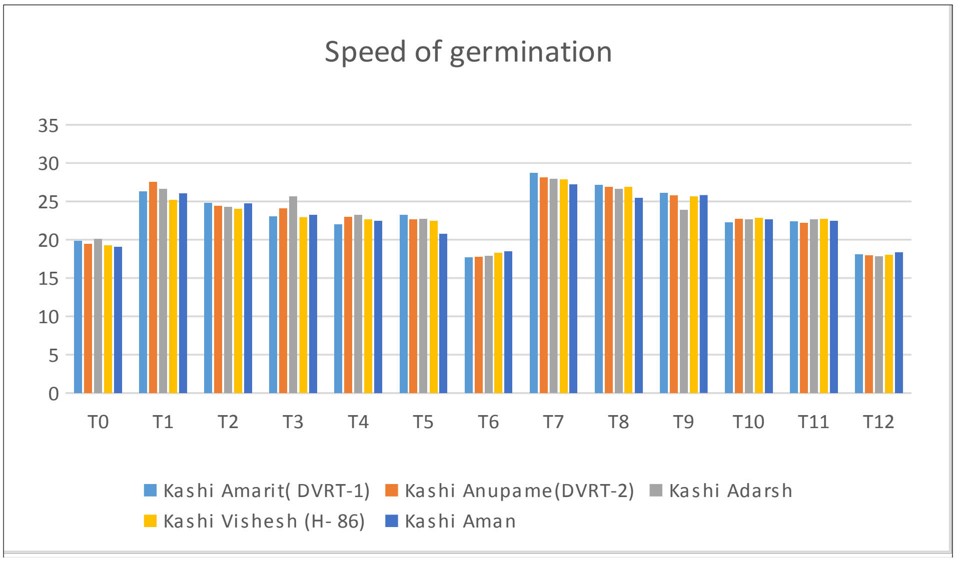

Fig 3.2(A): Histogram depicting performance of five varieties for Speed of Germination

3.3 Mean Germination Time

(A) Kashi Amarit: Data in table 2 exhibits a significant variation in mean germination time of tomato. It is evident from the table that significantly maximum increase in mean germination time occurs by T_1 (43.87) followed by T_7 (43.31), T_2 (41.87) while lowest mean germination time (35.37) was observed with T_{12}.

(B) Kashi Anupame: Data in table 3 exhibits a significant variation in mean germination time of tomato. It is evident from the table that significantly maximum increase in mean germination time occurs by T_1 (43.06) followed by T_7 (42.81), T_2 (42.12) while lowest mean germination time (35.50) was observed with T_{12}.

(C) Kashi Adarsh: Data in table 4 exhibits a significant variation in mean germination time of tomato. It is evident from the table that significantly maximum increase in mean germination time occurs by T_1 (43.00) followed by T_7 (42.18), T_2 (41.87) while lowest mean germination time (37.68) was observed with T_6.

(D) Kashi Vishesh: Data in table 5 exhibits a significant variation in mean germination time of tomato. It is evident from the table that significantly maximum increase in mean germination time occurs by T_1 (43.00) followed by T_7 (42.62), T_2 (41.87) while lowest mean germination time (37.12) was observed with T_6.

(E) Kashi Aman: Data in table 6 exhibits a significant variation in mean germination time of tomato. It is evident from the table that significantly maximum increase in mean germination time occurs by T_1 (43.12) followed by T_7 (42.12), T_9 (40.93) while lowest mean germination time (36.68) was observed with T_{12}.

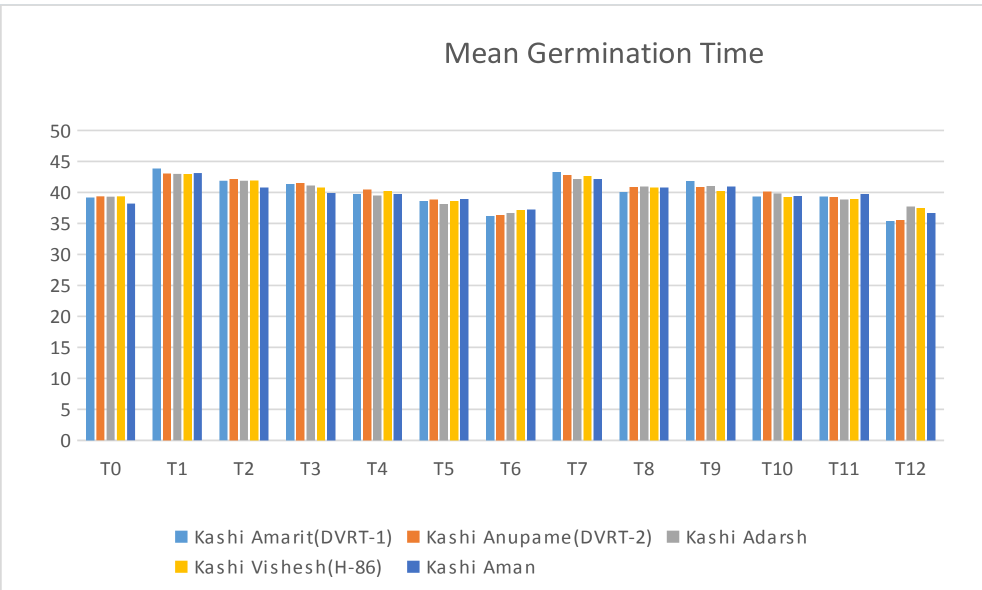

Fig 3.3(A): Histogram depicting performance of five varieties for Mean germination time

The seeds treated with nanoparticles (Titanium dioxide and Zinc oxide) at low concentrations showed highest Mean germination time because the particles diminish oxidative stress by promoting antioxidant enzyme activities in tomato seedlings.
Similar finding were also reported by Kaya *et al.*, (2008), Hassan *et al.*, (2012), Feizi *et al.*, (2013), Feizi *et al.*, (2013), Manzer H. Siddiqui and Mohamed H. Al-Whaibi (2013).
Hassan *et al.*, (2012) concluded that the proper concentration of nanosized titanium dioxide particles accelerated the germination process and vigor in wheat seeds and also nano titanium dioxide improved the mean germination time.

3.4 Root Length

(A) Kashi Amarit - Data in table 2 exhibits a significant variation in root length of tomato. It is evident from the table that significantly maximum increase in root length occurs by T_1 (10.04 cm) followed by T_2 (9.76 cm), T_7 (8.77 cm) while lowest root length (6.84 cm) was observed with unprimed control.

(B) Kashi Anupame - Data in table 3 exhibits a significant variation in root length of tomato. It is evident from the table that significantly maximum increase in root length occurs by T_1 (9.48 cm) followed by T_7 (8.93 cm), T_2 (8.93 cm) while lowest root length (7.37 cm) was observed with unprimed control.

(C) Kashi Adarsh – Data in table 4 exhibits a significant variation in root length of tomato. It is evident from the table that significantly maximum increase in root length occurs by T_1 (9.34 cm) followed by T_7 (8.60 cm), T_2 (8.58 cm) while lowest root length (7.60) was observed with T_6.

(D) Kashi Vishesh – Data in table 5 exhibits a significant variation in root length of tomato. It is evident from the table that significantly maximum increase in root length occurs by T_1 (9.51 cm) followed by T_7 (8.89 cm), T_2 (8.46 cm) while lowest root length (7.29 cm) was observed with unprimed control.

(E) Kashi Aman - Data in table 6 exhibits a significant variation in root length of tomato. It is evident from the table that significantly maximum increase in root length occurs by T_1 (9.86 cm) followed by T_7 (9.47 cm), T_2 (8.63 cm) while lowest root length (35.37) was observed with unprimed control.

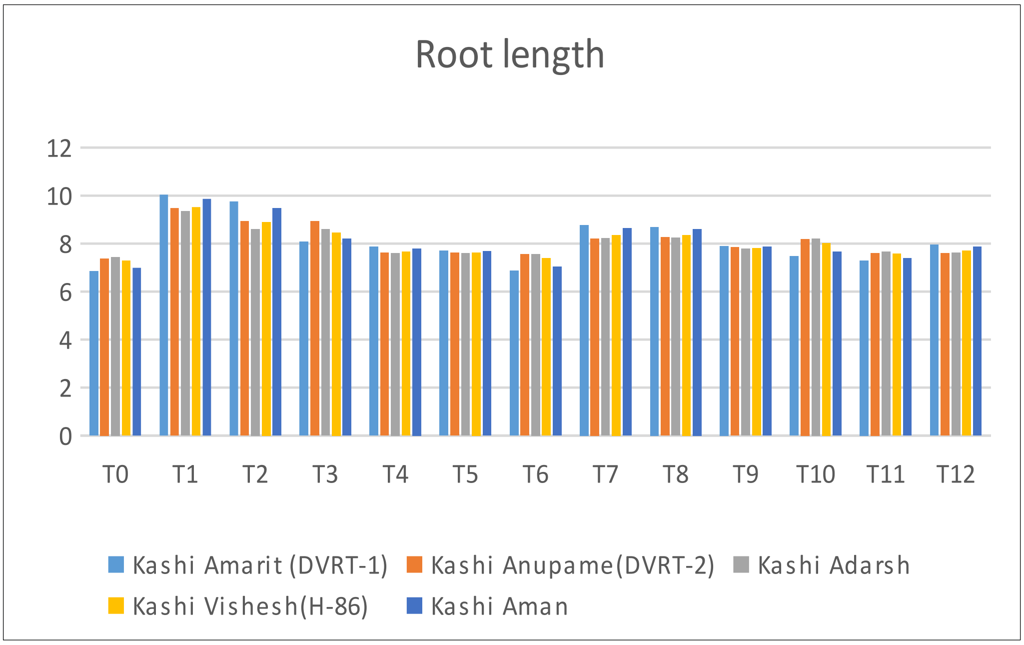

Fig 3.4(A): Histogram depicting performance of five varieties for Root length

The seeds treated with nanoparticles (Titanium dioxide and Zinc oxide) at low concentrations showed highest root length because of increase in root length as the metabolic and enzymatic activities of cells activate and hence an increase in meristematic cell division which ultimately lead to protrusion of seedlings.
Similar finding were also reported by Mahajan *et al.*, (2011), Moreno *et al.*, (2010), Wang *et al.*, (2012), Suriyaprabha *et al.*, (2012), Dhoke *et al.*, (2013), Dhoke *et al.*, (2013), Ramesh and Tarafdar (2013), Yugandhar and Savithramma (2013).
Ramesh and Tarafdar (2013) observed a significant increase in the plant biomass, shoot and root length, root area, chlorophyll content, total soluble leaf content, gum content in young seedlings of cluster bean when they were treated with biologically synthesized ZnO nanoparticles.

3.5 Shoot Length

(A) Kashi Amarit - Data in table 2 exhibits a significant variation in shoot length of tomato. It is evident from the table that significantly maximum increase in shoot length occurs by T_1 (5.56 cm) followed by T_7 (5.23 cm), T_0 (4.85 cm) while lowest shoot length (3.78 cm) was observed with T_{12}.

(B) Kashi Anupame - Data in table 3 exhibits a significant variation in shoot length of tomato. It is evident from the table that significantly maximum increase in shoot length occurs by T_1 (5.48 cm) followed by T_7 (5.32 cm), T_2 (5.05 cm) while lowest shoot length (3.92 cm) was observed with T_{12}.

(C) Kashi Adarsh – Data in table 4 exhibits a significant variation in shoot length of tomato. It is evident from the table that significantly maximum increase in shoot length occurs by

T_7 (5.40 cm) followed by T_1 (5.01 cm), T_2 (5.01 cm) while lowest shoot length (4.13 cm) was observed with T_{12}.

(D) Kashi Vishesh – Data in table 5 exhibits a significant variation in shoot length of tomato. It is evident from the table that significantly maximum increase in shoot length occurs by T_7 (5.20 cm) followed by T_1 (5.11 cm), T_2 (4.88 cm) while lowest shoot length (4.11 cm) was observed with T_{12}.

(E) Kashi Aman - Data in table 6 exhibits a significant variation in shoot length of tomato. It is evident from the table that significantly maximum increase in shoot length occurs by T_1 (5.40 cm) followed by T_7 (5.40 cm), T_2 (4.97 cm) while lowest shoot length (3.89 cm) was observed with T_{12}.

The seeds treated with nanoparticles (Titanium dioxide and Zinc oxide) at low concentrations showed highest shoot length because of increase in shoot length as the metabolic and enzymatic activities of cells activate and hence an increase in meristematic cell division which ultimately lead to protrusion of seedlings.
Similar finding were also reported by Morla *et al.*, (2011), Dhoke *et al.*, (2013), Dhoke *et al.*, (2013), Ramesh and Tarafdar (2013), Yugandhar and Savithramma (2013).
Yugandhar and Savithramma (2013) found that the biologically synthesized calcium carbonate nanoparticles were more effective in accelerating the growth parameters such as seed germination, seedling vigor index, root and shoot length, fresh and dry weight and relative water content of mung.

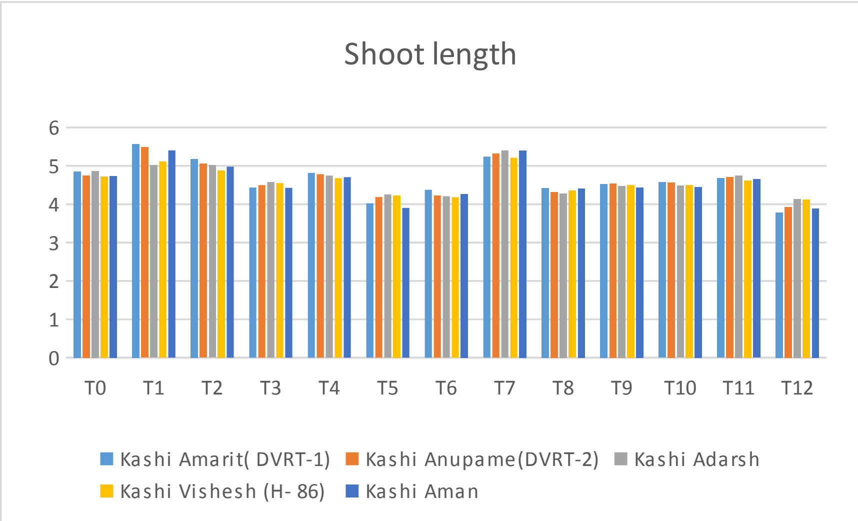

Fig 3.5(A): Histogram depicting performance of five varieties for Shoot length

3.6 Seedling Length

(A) Kashi Amarit - Data in table 2 exhibits a significant variation in seedling length of tomato. It is evident from the table that significantly maximum increase in seedling length occurs by T_1 (15.43 cm) followed by T_7 (15.03 cm), T_2 (14.47 cm) while lowest seedling length (11.47 cm) was observed with T_6.

(B) Kashi Anupame - Data in table 3 exhibits a significant variation in seedling length of tomato. It is evident from the table that significantly maximum increase in seedling length occurs by T_1 (14.60 cm) followed by T_7 (14.00 cm), T_2 (13.87 cm) while lowest seedling length (11.59 cm) was observed with T_{12}.

(C) Kashi Adarsh – Data in table 4 exhibits a significant variation in seedling length of tomato. It is evident from the table that significantly maximum increase in seedling length occurs by T_7 (14.17 cm) followed by T_1 (13.95 cm), T_2 (13.50 cm) while lowest seedling length (11.81 cm) was observed with T_6.

(D) Kashi Vishesh – Data in table 5 exhibits a significant variation in seedling length of tomato. It is evident from the table that significantly maximum increase in seedling length occurs by T_1 (14.36 cm) followed by T_7 (14.36 cm), T_2 (13.48 cm) while lowest seedling length (11.63 cm) was observed with T_6.

(E) Kashi Aman - Data in table 6 exhibits a significant variation in seedling length of tomato. It is evident from the table that significantly maximum increase in seedling length occurs by T_1 (14.85 cm) followed by T_7 (14.75 cm), T_2 (14.24 cm) while lowest seedling length (11.36 cm) was observed with T_6.
The seeds treated with nanoparticles (Titanium dioxide and Zinc oxide) at low concentrations showed highest seedling length because of increase in enzymatic activity and also improves the cell division process which results in high seedling length.
Similar finding were also reported by **Azimi *et al.*, (2013).**
Azimi *et al.*, (2013) through their results revealed that the exposure of wheat grass seeds to the low doses of nano titanium dioxide particles could promote the germination percentage and also the germination rate could be faster when compared with bulk sized titanium dioxide particles and control treatments. Also there was increase in root, shoot, seedlings lengths and root biomass.

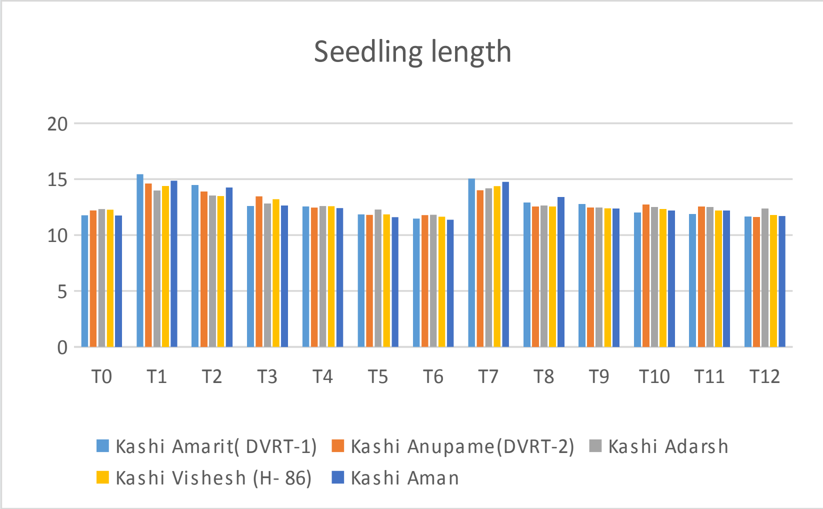

Fig 3.6(A): Histogram depicting performance of five varieties for Seedling length

3.7 Seedling Fresh Weight

(A) Kashi Amarit - Data in table 2 exhibits a significant variation in seedling fresh weight of tomato. It is evident from the table that significantly maximum increase in seedling fresh weight occurs by T_1 (2.03 g) followed by T_7 (2.03 g), T_3 (1.2 g) while lowest seedling fresh weight (1.69 g) was observed with T_{12}.

(B) Kashi Anupame - Data in table 3 exhibits a significant variation in seedling fresh weight of tomato. It is evident from the table that significantly maximum increase in seedling fresh weight occurs by T_1 (2.01 g) followed by T_7 (1.96 g), T_8 (1.91 g) while lowest seedling fresh weight (1.58 g) was observed with T_{12}.

(C) Kashi Adarsh – Data in table 4 exhibits a significant variation in seedling fresh weight of tomato. It is evident from the table that significantly maximum increase in seedling fresh weight occurs by T_7 (2.05 g) followed by T_1 (1.91 g), T_8 (1.89 g) while lowest seedling fresh weight (1.69 g) was observed with T_{12}.

(D) Kashi Vishesh – Data in table 5 exhibits a significant variation in seedling fresh weight of tomato. It is evident from the table that significantly maximum increase in seedling fresh weight occurs by T_7 (2.01 g) followed by T_1 (2.00 g), T_8 (1.95 g) while lowest seedling fresh weight (1.68 g) was observed with T_5.

(E) Kashi Aman - Data in table 6 exhibits a significant variation in seedling fresh weight of tomato. It is evident from the table that significantly maximum increase in seedling fresh weight occurs by T_1 (2.02 g) followed by T_7 (2.00 g), T_2 (1.90 g) while lowest seedling fresh weight (1.68 g) was observed with T_6.

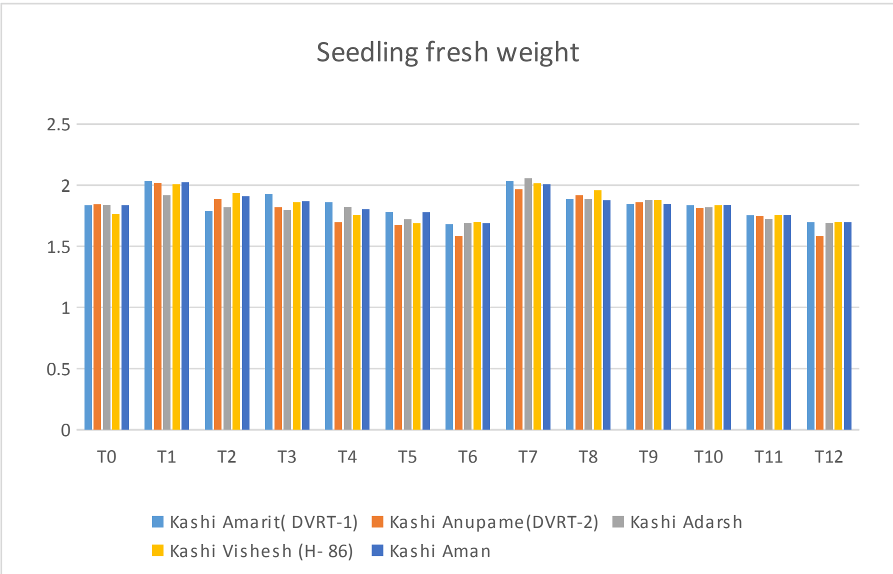

Fig 3.7(A): Histogram depicting performance of five varieties for Seedling fresh weight

The seeds treated with nanoparticles (Titanium dioxide and Zinc oxide) at low concentrations showed highest seedling fresh weight because they positively affect the xylem humidity and water translocation by attaching to the plant tissue and forming a cellulose layer which results in water use efficiency improvementand hence seedling fresh weight is improved.

Similar finding were also reported by Kaya *et al.*, (2008), Manzer H. Siddiqui and Mohamed H. Al-Whaibi (2013), Yugandhar and Savithramma (2013).

Yugandhar and Savithramma (2013) found that the biologically synthesized calcium carbonate nanoparticles were more effective in accelerating the growth parameters such as seed germination, seedling vigor index, root and shoot length, fresh and dry weight and relative water content of mung.

3.8 Seedling Dry Weight

(A) Kashi Amarit: Data in table 2 exhibits a significant variation in seedling dry weight of tomato. It is evident from the table that significantly maximum increase in seedling dry weight occurs by T_1 (0.025 mg) followed by T_7 (0.025 mg), T_8 (0.024 mg) while lowest seedling dry weight (0.012 mg) was observed with T_{12}.

(B) Kashi Anupame: Data in table 3 exhibits a significant variation in seedling dry weight of tomato. It is evident from the table that significantly maximum increase in seedling dry weight occurs by T_1 (0.027 mg) followed by T_7 (0.027 mg), T_2 (0.026 mg) while lowest seedling dry weight (0.012 mg) was observed with T_{12}.

(C) Kashi Adarsh: Data in table 3 exhibits a significant variation in seedling dry weight of tomato. It is evident from the table that significantly maximum increase in seedling dry weight occurs by T_1 (0.027 mg) followed by T_7 (0.027 mg), T_8 (0.025 mg) while lowest seedling dry weight (0.012 mg) was observed with T_{12}.

(D) Kashi Vishesh: Data in table 4 exhibits a significant variation in seedling dry weight of tomato. It is evident from the table that significantly maximum increase in seedling dry weight occurs by T_1 (0.027 mg) followed by T_7 (0.027 mg), T_2 (0.025 mg) while lowest seedling dry weight (0.012 mg) was observed with T_{12}.

(E) Kashi Aman: Data in table 5 exhibits a significant variation in seedling dry weight of tomato. It is evident from the table that significantly maximum increase in seedling dry weight occurs by T_1 (0.027 mg) followed by T_7 (0.026 mg), T_3 (0.025 mg) while lowest seedling dry weight (0.015 mg) was observed with unprimed control.

The seeds treated with nanoparticles (Titanium dioxide and Zinc oxide) at low concentrations showed highest seedling dry weight as TiO_2 NP's regulates enzymes activity involved in nitrogen metabolism such as nitrate reductase, glutamate dehydrogenase, glutamine synthase, and glutamic-pyruvic transaminase that helps the seedlings to absorb nitrate and favors conversion of inroganic nitrogen to organic nitrogen in the form of protein and chlorophyll, that could increase dry weight.

Similar finding were also reported by Kasra *et al.*, (2011) [39], Kasra Maroufi *et al.*, (2011) [39], Manzer H Kasra *et al.*, (2011) [39] stated that the nano priming of green gram seeds with titanium dioxide nanoparticles could improve the germination percentage, seedling dry weight and seedling vigor when compared with control.

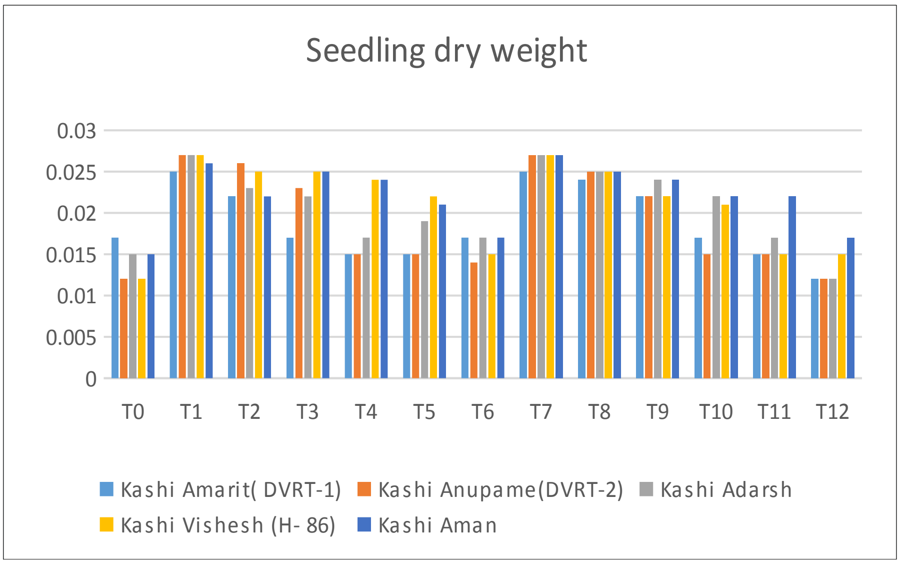

Fig 3.8(A): Histogram depicting performance of five varieties for Seedling dry weight

3.9 Vigour Index – I

(A) Kashi Amarit - Data in table 2 exhibits a significant variation in vigor index -I of tomato. It is evident from the table that significantly maximum increase in vigor index –I occurs by T_7 (1087.50) followed by T_1 (1062.50), T_8 (967.50) while lowest vigor index -I (580) was observed with T_{12}.

(B) Kashi Anupame – Data in table 3 exhibits a significant variation in vigor index -I of tomato. It is evident from the table that significantly maximum increase in vigor index –I occurs by T_7 (1080.75) followed by T_1 (1026.50), T_8 (955.25) while lowest vigor index -I (577.50) was observed with T_{12}.

(C) Kashi Adarsh – Data in table 4 exhibits a significant variation in vigor index -I of tomato. It is evident from the table that significantly maximum increase in vigor index –I occurs by T_1 (1039.68) followed by T_7 (1018.00), T_8 (942.68) while lowest vigor index -I (581.87) was observed with T_{12}.

(D) Kashi Vishesh – Data in table 5 exhibits a significant variation in vigor index -I of tomato. It is evident from the table that significantly maximum increase in vigor index –I occurs by T_1 (1033.75) followed by T_7 (1023.25), T_8 (939.00) while lowest vigor index -I (583.25) was observed with T_{12}.

(E) Kashi Aman Data in table 6 exhibits a significant variation in vigor index -I of tomato. It is evident from the table that significantly maximum increase in vigor index –I occurs by T_1 (1030.50) followed by T_7 (1025.50), T_2 (937.50) while lowest vigor index -I (583.50) was observed with T_{12}.

The seeds treated with nanoparticles (Titanium dioxide and Zinc oxide) at low concentrations showed highest Vigour index-I because of balanced free radical generation, enzyme activity, endogenous harmone levels, cell moisture availability and the degree of oxidative stress will positively affect the seedlings.NP's also improve biochemical and physiological properties of seeds which improve vigour.Enhanced physiological performance could be attributed to quenching of free radicals.Smaller size of the NP's would have easily entered through the cracks present on the outer seed surface,reacted with free radicals resulting in enhanced seed vigour.

Similar finding were also reported by Hassan *et al.*, (2012), Prasad *et al.*, (2012).

Prasad *et al.*, (2012) showed that the nanoscale zinc oxide particles could be able to promote germination percentage, seedling vigor, plant height, chlorophyll content in peanut.

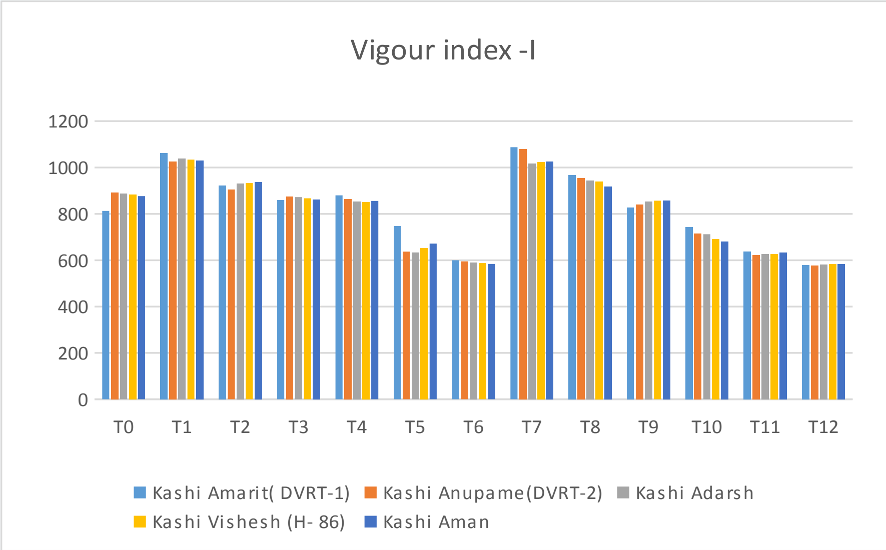

Fig 3.9(A): Histogram depicting performance of five varieties for Vigour index-I

3.10 Vigour Index – II

(A) Kashi Amarit - Data in table 2 exhibits a significant variation in vigor index -II of tomato. It is evident from the table that significantly maximum increase in vigor index –II occurs by T_1 (8.88) followed by T_7 (8.83), T_2 (8.34) while lowest vigor index -II (5.91) was observed with unprimed control.

(B) Kashi Anupame - Data in table 3 exhibits a significant variation in vigor index -II of tomato. It is evident from the table that significantly maximum increase in vigor index –II occurs by T_1 (8.64) followed by T_7 (8.60), T_8 (8.33) while lowest vigor index -II (6.11) was observed with T_{12}.

(C) Kashi Adarsh – Data in table 4 exhibits a significant variation in vigor index -II of tomato. It is evident from the table that significantly maximum increase in vigor index –II occurs by T_1 (9.74) followed by T_7 (9.59), T_8 (9.20) while lowest vigor index -II (6.92) was observed with T_{12}.

(D) Kashi Vishesh – Data in table 5 exhibits a significant variation in vigor index -II of tomato. It is evident from the table that significantly maximum increase in vigor index –II occurs by T_1 (8.57) followed by T_7 (8.49), T_8 (8.18) while lowest vigor index -II (5.70) was observed with T_6.

(E) Kashi Aman - Data in table 6 exhibits a significant variation in vigor index -II of tomato. It is evident from the table that significantly maximum increase in vigor index –II occurs by T_1 (8.99) followed by T_7 (8.73), T_2 (8.38) while lowest vigor index -II (5.51) was observed with T_6.

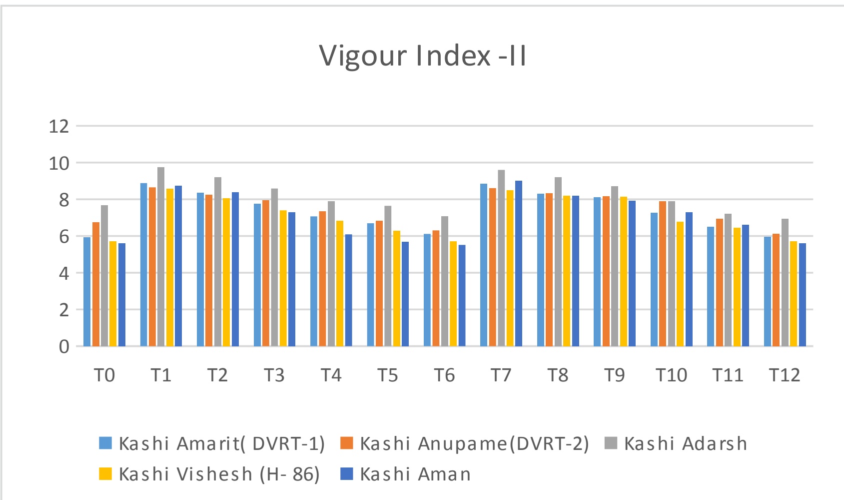

Fig 3.10(A): Histogram depicting performance of five varieties for Vigour index-II

The seeds treated with nanoparticles (Titanium dioxide and Zinc oxide) at low concentrations showed highest Vigour index-II because of proline which are highly hydrophilic and have an important role in the improvement of plant tolerance to environmental stresses and protection of cellular structures during cell dehydration by reducing the water potential and keeping the activities of some biological macromolecules.Its accumulation in plant is associated with reducing damage to the cell membranes and proteins.
Similar finding were also reported by Yadav and Yadav (2005), Kasra *et al.*, (2011) [39], Kasra Maroufi *et al.*, (2011) [39], Hassan *et al.*, (2012), Prasad *et al.*, (2012).
Hassan *et al.*, (2012) concluded that the proper concentration of nanosized titanium dioxide particles accelerated the germination process and vigor in wheat seeds and also nano titanium dioxide improved the mean germination time.

3.11 Electrical Conductivity of Seed Leachate

(A) Kashi Amarit: Data in table 2 exhibits a significant variation in electrical conductivity of seed leachate of tomato. It is evident from the table that significantly maximum increase in electrical conductivity of seed leachates occurs by T_6 (86.06) followed by T_{12} (83.87), T_5 (80.87) while lowest electrical conductivity of seed leachates (69.87) was observed with T_1.

(B) Kashi Anupame: Data in table 3 exhibits a significant variation in electrical conductivity of seed leachate of tomato. It is evident from the table that significantly maximum increase in electrical conductivity of seed leachates occurs by T_{12} (85.51) followed by T_6 (84.42), T_5 (82.37) while lowest electrical conductivity of seed leachates (70.03) was observed with T_7.

(C) Kashi Adarsh: Data in table 4 exhibits a significant variation in electrical conductivity of seed leachate of tomato. It is evident from the table that significantly maximum increase in electrical conductivity of seed leachates occurs by T_{12} (84.11) followed by T_6 (83.52), T_5 (82.24) while lowest electrical conductivity of seed leachates (69.13) was observed with T_7.

(D) Kashi Vishesh: Data in table 5 exhibits a significant variation in electrical conductivity of seed leachate of tomato. It is evident from the table that significantly maximum increase in electrical conductivity of seed leachates occurs by T_6 (83.90) followed by T_{12} (83.90), T_5 (82.41) while lowest electrical conductivity of seed leachates (68.66) was observed with T_1.

(E) Kashi Aman: Data in table 6 exhibits a significant variation in electrical conductivity of seed leachate of tomato. It is evident from the table that significantly maximum increase in electrical conductivity of seed leachates occurs by T_{12} (84.98) followed by T_6 (84.25), T_5 (84.11) while lowest electrical conductivity of seed leachates (70.11) was observed with T_1.
The seeds treated with nanoparticles (Titanium dioxide and Zinc oxide) at high concentrations showed more leachate conductivity and also the amount of soluble carbohydrates leached out from seeds is more in nanoparticles treatments at high concentrations and this is due to membrane deterioration.Cell membrane integrity can be affected by two mechanisms at varying extents: nanoparticle adsorption to the membrane and membrane fracture.Also using anionic and cationic functionalized nanoparticles fracture the membrane, disrupting its integrity.
Similar finding were also reported by Prete *et al.*, (1994).
Prete *et al.*, (1994) detected a highly significant negative correlation between the electrical conductivity evaluation and the field emergence of soybean seedling.

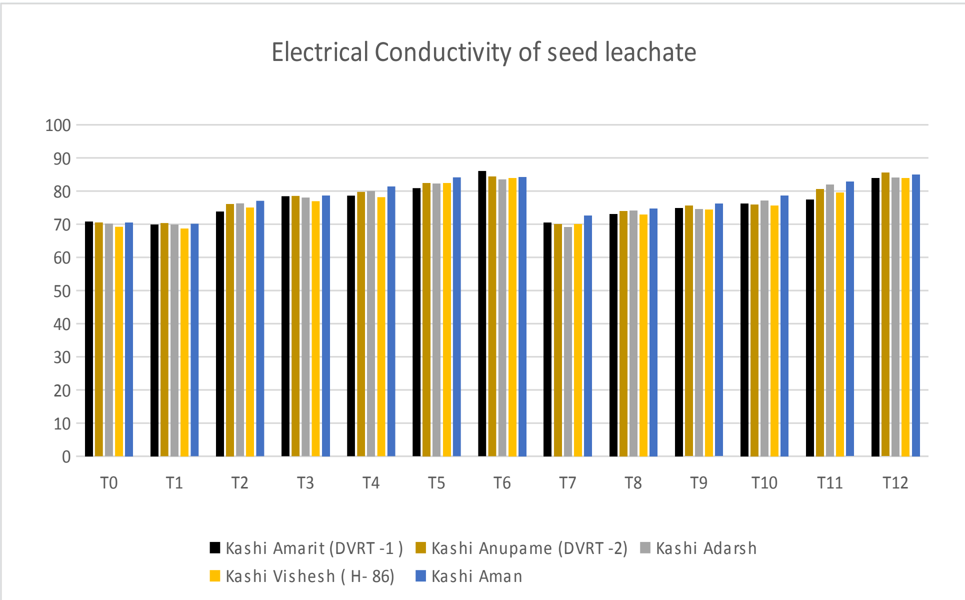

Fig 3.11(A): Histogram depicting performance of five varieties for Electrical Conductivity of seed leachate

3.12 Seed Metabolic Efficiency

(A) Kashi Amarit - Data in table 2 exhibits a significant variation in seed metabolic efficiency of tomato. It is evident from the table that significantly maximum increase in seed metabolic efficiency occurs by T_6 (0.175) followed by T_{12} (0.175), T_4 (0.155) while lowest seed metabolic efficiency (0.115) was observed with T_7.

(B) Kashi Anupame - Data in table 3 exhibits a significant variation in seed metabolic efficiency of tomato. It is evident from the table that significantly maximum increase in seed metabolic efficiency occurs by T_6 (0.170) followed by T_{12} (0.165), T_4 (0.152) while lowest seed metabolic efficiency (0.115) was observed with T_7.

(C) Kashi Adarsh – Data in table 4 exhibits a significant variation in seed metabolic efficiency of tomato. It is evident from the table that significantly maximum increase in seed metabolic efficiency occurs by T_6 (0.167) followed by T_{12} (0.162), T_5 (0.147) while lowest seed metabolic efficiency (0.115) was observed with T_7.

(D) Kashi Vishesh – Data in table 5 exhibits a significant variation in seed metabolic efficiency of tomato. It is evident from the table that significantly maximum increase in seed metabolic efficiency occurs by T_{12} (0.170) followed by T_6 (0.165), T_4 (0.147) while lowest seed metabolic efficiency (0.117) was observed with T_7.

(E) Kashi Aman - Data in table 6 exhibits a significant variation in seed metabolic efficiency of tomato. It is evident from the table that significantly maximum increase in seed metabolic efficiency occurs by T_{12} (0.185) followed by T_6 (0.175), T_{11} (0.156) while lowest seed metabolic efficiency (0.115) was observed with T_1.

The seeds treated with nanoparticles (Titanium dioxide and Zinc oxide) at high concentrations showed high seed metabolic efficiency because of physiochemical properties of NP's that boost the seed metabolism and they also enter into plant tissue and interfere with different metabolic activities.

Similar finding were also reported by Rao (1993).

Rao (1993) reported that lower value of seed metabolic efficiency indicates the higher efficiency of seed because more dry matter will be produced from the reserves. It helps the seedlings to utilize lesser amount of reserve food for dry matter production.

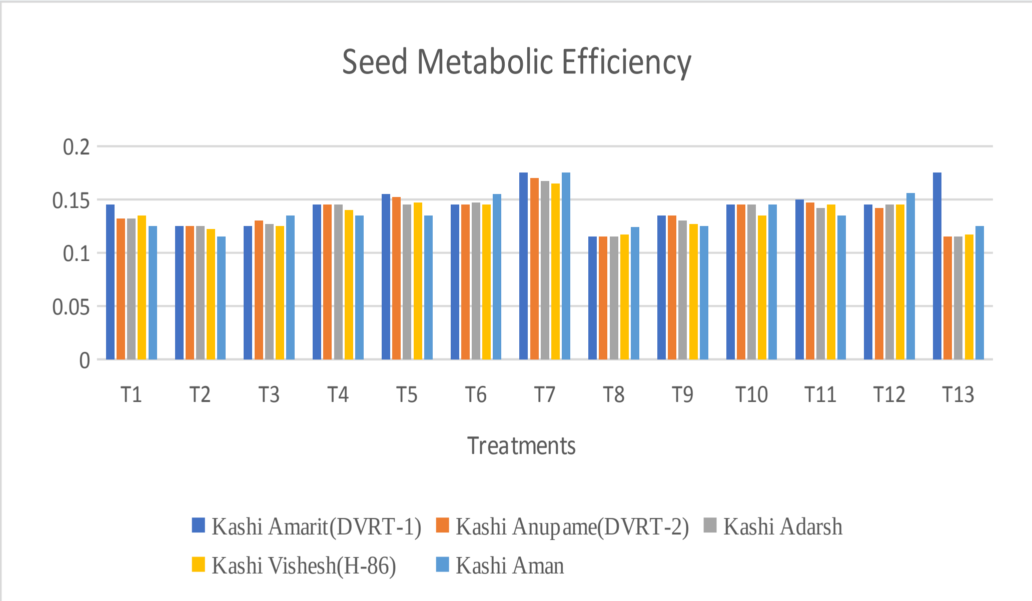

Fig 3.12(A): Histogram depicting performance of five varieties for Seed metabolic efficiency

3.13 Field Emergence Index

(A) Kashi Amarit - Data in table 2 exhibits a significant variation in field emergence index of tomato. It is evident from the table that significantly maximum increase in field emergence index occurs by T_1 (93.270) followed by T_7 (92.150), T_0 (92.755) while lowest field emergence index (74.590) was observed with T_6.

(B) Kashi Anupame -Data in table 3 exhibits a significant variation in field emergence index of tomato. It is evident from the table that significantly maximum increase in field emergence index occurs by T_7 (93.695) followed by T_1 (93.295), T_0 (92.600) while lowest field emergence index (82.150) was observed with T_{12}.

(C) Kashi Adarsh – Data in table 4 exhibits a significant variation in field emergence index of tomato. It is evident from the table that significantly maximum increase in field emergence index occurs by T_7 (93.825) followed by T_1 (93.675), T_0 (92.985) while lowest field emergence index (84.945) was observed with T_{12}.

(D) Kashi Vishesh - Data in table 5 exhibits a significant variation in field emergence index of tomato. It is evident from the table that significantly maximum increase in field emergence index occurs by T_1 (94.405) followed by T_7 (94.125), T_0 (93.575) while lowest field emergence index (81.160) was observed with T_{12}.

(E) Kashi Aman -Data in table 6 exhibits a significant variation in field emergence index of tomato. It is evident from the table that significantly maximum increase in field emergence index occurs by T_7 (93.965) followed by T_1 (93.535), T_0 (93.165) while lowest field emergence index (82.510) was observed with T_{12}.

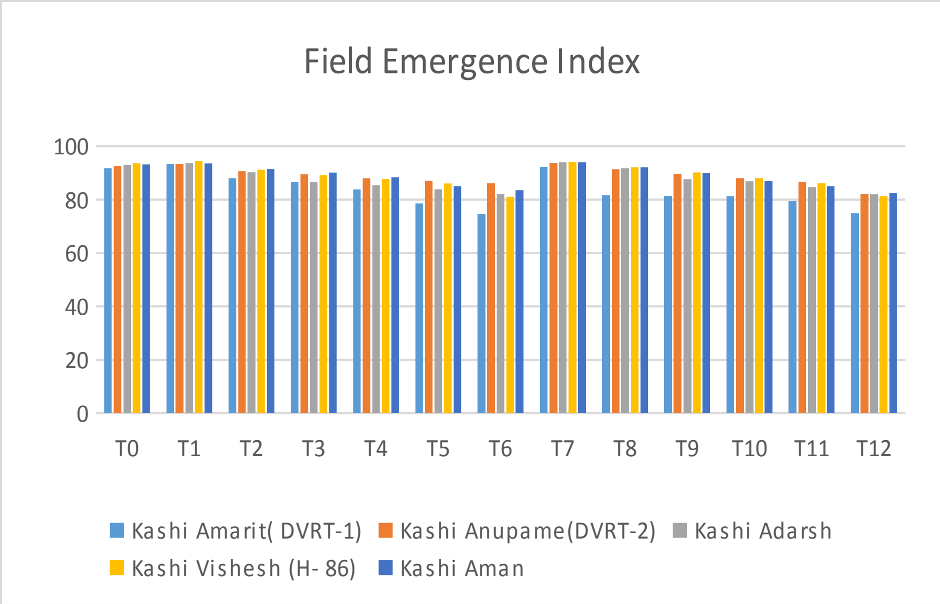

Fig 3.13(A): Histogram depicting performance of five varieties for field emergence index

The seeds treated with nanoparticles (Titanium dioxide and Zinc oxide) at lower concentrations showed high field emergence index because of high cellular metabolism, release of antioxidant enzymes that can withstand against stress, meristematic cell division.

Similar finding were also reported by Donna Krupa (2002), Yadav and Yadav (2005), Arif *et al.*,(2008).

Arif *et al.*, (2008) there are more reports about seed priming effect on different plants. It was reported that soyabean seed priming made better seedling emergence and yield improvement.

Table 1: Analysis of Variance for 13 seedling characters in Tomato

S. No	Characters	Mean Sum of Squares									
		Treatments (df = 12)					Error (df=39)				
		V1	V2	V3	V4	V5	V1	V2	V3	V4	V5
1.	Germination %	50.39	37.41	35.71	41.94	43.66	4.12	1.44	0.36	0.78	1.47
2.	Speed of germination	45.74	45.79	40.37	37.88	35.85	1.67	0.79	0.73	0.68	0.68
3.	Mean germination time	24.73	20.65	14.19	13.25	13.07	1.80	1.19	1.46	1.03	1.25
4.	Root length	3.926	1.724	1.260	1.659	3.001	0.45	0.531	0.080	0.083	0.081
5.	Shoot length	0.959	0.803	0.575	0.456	0.893	0.14	0.039	0.049	0.023	0.024
6.	Seedling length	7.155	3.506	1.923	3.304	5.804	0.11	0.089	0.147	0.081	0.103
7.	Seedling fresh weight	0.049	0.077	0.046	0.052	0.042	0.009	0.004	0.003	0.009	0.005
8.	Seedling dry weight	4.038	6.543	3.715	5.234	3.665	1.105	1.424	1.034	1.938	1.061
9.	Vigour index - I	106051.92	113085.11	105481.94	104257.09	101334.30	1340.38	1513.26	637.780	280.26	233.587
10.	Vigour index - II	4.657	3.079	3.781	4.809	6.696	0.130	0.237	0.254	0.073	0.089
11.	Electrical conductivity	102.310	108.969	109.825	110.289	107.437	2.477	2.345	1.825	3.228	1.950
12.	Seed metabolic efficiency	0.003	0.009	0.009	0.007	0.005	6.412	5.193	2.723	8.841	6.341
		Treatments (df = 12)					Error (df=36)				
13.	Field emergence index	159.422	43.083	73.095	78.693	63.992	1.362	0.924	0.796	0.331	0.455

Table 2: Mean Performance of 13 Seed quality parameters VARIETY- 1 {KASHI AMARIT(DVRT-1)}

S.No.	Germination %	Speed of Germina-tion	Mean Germination Time	Root Length (cm)	Shoot length (cm)	Seedling length (cm)	Seedling Fresh Weight (g)	Seedling dry weight (mg)	Vigour index-I	Vigour index -II	EC	SME	FEI
Control	76.50	19.87	39.18	6.84	4.85	11.76	1.83	0.017	812.50	5.91	70.87	0.140	91.755
TiO_2 25mg @6 hrs	84.00	27.12	43.87	10.04	5.56	15.43	2.03	0.025	1062.50	8.88	69.87	0.125	93.270
TiO_2 50mg @6 hrs	80.00	24.81	41.87	8.77	5.17	14.47	1.78	0.022	922.50	8.34	73.81	0.125	87.965
TiO_2 75mg @6 hrs	78.00	23.06	41.37	8.08	4.43	12.59	1.92	0.017	860.00	7.75	78.43	0.145	86.595
TiO_2 100mg @6 hrs	79.00	22.00	39.68	7.86	4.81	12.55	1.85	0.015	880.00	7.06	78.62	0.155	83.795
$TiO_2$150mg @6 hrs	82.00	23.25	38.56	7.70	4.02	11.84	1.78	0.015	747.50	6.69	80.87	0.145	78.525
TiO_2 200mg @6 hrs	78.00	17.68	36.18	6.86	4.37	11.47	1.67	0.017	600.00	6.11	86.06	0.175	74.590
ZnO 25mg @6 hrs	90.00	28.68	43.31	9.76	5.23	15.03	2.03	0.025	1087.50	8.83	70.50	0.115	92.150
ZnO 50mg @6 hrs	82.75	26.31	40.06	8.69	4.42	12.89	1.88	0.024	967.50	8.30	73.11	0.135	81.605
ZnO 75mg @6 hrs	81.25	26.12	41.813	7.90	4.52	12.77	1.84	0.022	827.50	8.10	74.93	0.145	81.425
ZnO 100mg @6 hrs	78.25	22.25	39.375	7.46	4.57	12.00	1.83	0.017	742.50	7.27	76.18	0.150	81.105
ZnO 150mg @6 hrs	83.50	22.37	39.375	7.29	4.67	11.85	1.75	0.015	637.50	6.49	77.43	0.145	79.495
ZnO 200mg @6 hrs	80.75	18.06	35.37	7.95	3.78	11.66	1.69	0.012	580.00	5.95	83.87	0.175	74.750
G mean	81.076	23.202	40.005	8.093	4.649	12.796	1.841	0.018	825.192	7.362	76.508	0.144	83.617
SE (d)	1.436	0.914	0.948	0.479	0.270	0.234	0.067	0.743	25.88	0.254	0.786	1.790	0.825
SEM +	1.015	0.646	0.670	0.338	0.191	0.165	0.047	0.525	18.30	0.180	1.112	1.266	0.583
CD @ 5%	2.906	1.851	1.919	0.970	0.547	0.475	0.090	0.005	52.375	0.515	2.251	0.014	1.673
CV	2.50	5.57	3.35	8.37	8.22	2.59	3.41	5.49	4.43	4.88	2.05	5.55	1.39

Note: EC-Electrical conductivity **SME**- Seed metabolic efficiency **FEI**- Field emergence index

Table 3: Mean Performance of 13 Seed quality parameters VARIETY -2 {KASHI ANUPAME(DVRT-2)}

S.No.	Germination %	Speed of Germina-tion	Mean GerminationTime	Root Length (cm)	Shoot length (cm)	Seedling length (cm)	Seedling Fresh Weight (g)	Seedling dry weight (mg)	Vigour index –I	Vigour index -II	EC	SME	FEI
Control	77.28	19.42	39.37	7.37	4.74	12.19	1.84	0.013	892.50	6.75	70.53	0.132	92.600
TiO_2 25mg @6 hrs	86.03	27.50	43.06	9.48	5.48	14.60	2.01	0.027	1026.50	8.64	70.34	0.125	93.295
TiO_2 50mg @6 hrs	80.96	24.37	42.12	8.92	5.05	13.87	1.88	0.026	905.00	8.23	76.12	0.130	90.675
TiO_2 75mg @6 hrs	78.12	24.04	41.50	8.26	4.49	13.45	1.81	0.023	875.00	7.94	78.53	0.145	89.455
TiO_2 100mg @6 hrs	78.80	22.93	40.50	7.62	4.77	12.45	1.69	0.015	865.00	7.34	79.75	0.152	87.915
$TiO_2$150mg @6 hrs	80.97	22.62	38.81	7.62	4.18	11.80	1.67	0.015	636.75	6.81	82.37	0.145	87.045
TiO_2 200mg @6 hrs	79.79	17.78	36.31	7.54	4.22	11.78	1.59	0.014	595.00	6.30	84.42	0.170	85.895
ZnO 25mg @6 hrs	88.23	28.09	42.81	8.93	5.32	14.00	1.96	0.027	1080.75	8.60	70.03	0.115	93.695
ZnO 50mg @6 hrs	82.47	26.87	40.87	8.20	4.32	12.53	1.91	0.025	955.25	8.33	74.02	0.135	91.325
ZnO 75mg @6 hrs	82.45	25.79	40.875	7.84	4.53	12.43	1.85	0.022	840.25	8.14	75.55	0.145	89.625
ZnO 100mg @6 hrs	79.90	22.68	40.125	8.19	4.56	12.70	1.81	0.015	715.75	7.89	75.87	0.147	87.840
ZnO 150mg @6 hrs	82.24	22.21	39.250	7.61	4.71	12.53	1.74	0.015	622.75	6.94	80.65	0.142	86.485

ZnO 200mg @6 hrs	80.17	17.96	35.50	7.60	3.92	11.59	1.58	0.012	577.50	6.11	85.51	0.165	82.150
G mean	81.343	23.256	40.086	8.095	4.641	12.766	1.799	0.019	814.461	7.543	77.210	0.142	89.076
SE (d)	0.848	0.632	0.773	0.515	0.139	0.210	0.044	0.843	27.50	0.344	1.082	1.611	0.679
SEM +	0.600	0.446	0.546	0.364	0.098	0.149	0.031	0.596	19.45	0.243	0.765	1.139	0.480
CD @ 5%	1.717	1.278	1.564	1.042	0.283	0.427	0.089	0.007	55.646	0.696	2..190	0.013	1.375
CV	1.47	3.84	2.72	9.00	4.25	2.33	3.26	5.96	4.77	6.45	1.98	5.04	1.07

Note: EC-Electrical conductivity **SME**- Seed metabolic efficiency **FEI**- Field emergence index

Table 4: Mean Performance of 13 Seed quality parameters VARIETY- 3 (KASHI ADARSH)

S.No.	Germination %	Speed of Germina-tion	Mean Germination Time	Root Length (cm)	Shoot Length (cm)	Seedling length (cm)	Seedling Fresh Weight (g)	Seedling dry weight (mg)	Vigour index - I	Vigour index -II	EC	SME	FEI
Control	77.49	20.12	39.31	7.44	4.86	12.31	1.83	0.015	887.75	7.65	70.15	0.132	92.985
TiO_2 25mg @6 hrs	86.58	26.63	43.00	9.34	5.01	13.95	1.91	0.027	1039.68	9.74	69.88	0.125	93.675
TiO_2 50mg @6 hrs	81.33	24.29	41.87	8.58	5.01	13.50	1.81	0.023	930.12	9.19	76.27	0.127	90.135
TiO_2 75mg @6 hrs	78.29	25.62	41.12	8.22	4.57	12.79	1.79	0.022	872.50	8.57	78.04	0.145	86.555
TiO_2 100mg @6 hrs	78.63	23.21	39.50	7.61	4.74	12.58	1.82	0.017	852.62	7.88	79.96	0.145	85.335
$TiO_2$150mg @6 hrs	80.67	22.68	38.12	7.60	4.25	12.27	1.71	0.019	633.25	7.64	82.24	0.147	83.825
TiO_2 200mg @6 hrs	80.08	17.87	36.68	7.56	4.20	11.81	1.70	0.017	590.62	7.06	83.52	0.167	82.105
ZnO 25mg @6 hrs	87.68	27.94	42.18	8.60	5.40	14.17	2.05	0.027	1018.00	9.59	69.13	0.115	93.825
ZnO 50mg @6 hrs	82.39	26.60	40.93	8.24	4.27	12.64	1.89	0.025	942.68	9.20	74.08	0.130	91.595
ZnO 75mg @6 hrs	82.09	23.88	41.06	7.78	4.47	12.43	1.88	0.024	852.62	8.69	74.61	0.145	87.550
ZnO 100mg @6 hrs	79.96	22.61	39.81	8.20	4.47	12.49	1.81	0.022	711.81	7.89	77.16	0.142	86.820
ZnO 150mg @6 hrs	82.29	22.61	38.81	7.66	4.74	12.46	1.72	0.017	626.25	7.21	81.98	0.145	84.545
ZnO 200mg @6 hrs	80.10	17.82	37.68	7.61	4.13	12.37	1.69	0.012	581.87	6.92	84.11	0.162	81.945
G mean	81.355	23.227	40.009	8.038	4.628	12.756	1.818	0.020	810.754	8.253	77.015	0.140	87.761
SE (d)	0.426	0.607	0.854	0.632	0.156	0.271	0.0387	0.719	17.85	0.356	0.955	1.166	0.630
SEM +	0.301	0.429	0.604	0.141	0.110	0.191	0.027	0.508	12.62	0.251	0.675	0.825	0.446
CD @ 5%	0.862	1.229	1.728	0.403	0.317	0.549	0.067	0.003	36.128	0.721	1.933	0.004	1.279
CV	0.74	3.69	3.02	3.50	4.78	3.00	2.52	4.50	3.11	6.10	1.75	3.70	1.01

Note: EC-Electrical conductivity **SME**- Seed metabolic efficiency **FEI**- Field emergence index

Table 5: Mean Performance of 13 Seed quality parameters VARIETY – 4 {KASHI VISHESH(H-86)}

S.No.	Germination %	Speed of Germina-tion	Mean Germination Time	Root Length(cm)	Shoot Length (cm)	Seedling Length (cm)	Seedling Fresh Weight (g)	Seedling dry weight (mg)	Vigour index - I	Vigour index - II	EC	SME	FEI
Control	76.87	19.25	39.37	7.29	4.71	12.26	1.76	0.012	883.25	5.71	69.22	0.135	93.575
TiO_2 25mg @6 hrs	84.93	26.87	43.00	9.51	5.11	14.36	2.00	0.027	1033.75	8.57	68.66	0.122	94.405
TiO_2 50mg @6 hrs	80.21	24.00	41.87	8.46	4.88	13.48	1.93	0.025	933.00	8.05	75.02	0.125	91.215
TiO_2 75mg @6 hrs	78.54	22.93	40.81	8.36	4.55	13.20	1.85	0.024	867.00	7.39	76.93	0.140	89.125

TiO_2 100mg @6 hrs	78.891	22.62	40.18	7.67	4.67	12.57	1.75	0.024	852.00	6.83	78.16	0.147	87.685
$TiO_2$150mg @6 hrs	81.563	22.43	38.62	7.63	4.22	11.84	1.68	0.022	652.50	6.27	82.41	0.145	86.015
TiO_2 200mg @6 hrs	79.20	18.25	37.12	7.38	4.17	11.63	1.69	0.015	587.75	5.70	83.90	0.165	81.100
ZnO 25mg @6 hrs	89.34	27.87	42.62	8.89	5.20	14.36	2.01	0.027	1023.25	8.49	70.08	0.117	94.125
ZnO 50mg @6 hrs	83.23	25.62	40.75	8.35	4.34	12.52	1.95	0.024	939.00	8.18	72.97	0.127	92.060
ZnO 75mg @6 hrs	82.56	25.18	40.25	7.81	4.50	12.38	1.87	0.022	857.00	8.13	74.46	0.135	90.155
ZnO 100mg @6 hrs	79.77	22.81	39.22	8.02	4.50	12.31	1.83	0.021	691.50	6.77	75.66	0.145	87.820
ZnO 150mg @6 hrs	82.14	22.68	38.87	7.57	4.61	12.15	1.75	0.015	627.75	6.43	79.50	0.145	86.055
ZnO 200mg @6 hrs	80.31	18.00	37.42	7.69	4.11	11.77	1.69	0.015	583.25	5.72	83.90	0.170	81.160
G mean	81.354	22.966	40.011	8.052	4.586	12.683	1.832	0.021	810.076	7.098	76.225	0.139	88.807
SE (d)	0.628	0.583	0.719	0.203	0.107	0.201	0.067	0.984	11.83	0.191	1.270	2.102	0.406
SEM +	0.444	0.412	0.508	0.144	0.075	0.142	0.047	0.696	8.37	0.135	0.898	1.486	0.287
CD @ 5%	1.271	1.182	1.456	0.412	0.215	0.406	0.045	0.004	23.949	0.388	2.570	0.014	0.824
CV	1.09	3.59	2.54	3.57	3.27	2.24	1.70	4.55	2.06	3.81	2.35	6.71	0.64

Note: EC-Electrical conductivity **SME**- Seed metabolic efficiency **FEI**- Field emergence index

Table 6: Mean Performance of 13 Seed quality parameters VARIETY – 5 (KASHI AMAN)

S.No.	Germination %	Speed of Germina-tion	Mean Germination Time	Root Length (cm)	Shoot Length (cm)	Seedling length(cm)	Seedling Fresh Weight (g)	Seedling dry weight (mg)	Vigour index - I	Vigour index -II	EC	SME	FEI
Control	77.00	19.06	38.18	6.99	4.73	11.74	1.83	0.015	876.50	5.60	70.54	0.125	93.165
TiO_2 25mg @6 hrs	84.00	26.06	43.12	9.86	5.40	14.85	2.02	0.026	1030.50	8.73	70.11	0.115	93.535
TiO_2 50mg @6 hrs	80.12	24.75	40.75	8.63	4.97	14.24	1.90	0.022	937.50	8.38	77.02	0.135	91.445
TiO_2 75mg @6 hrs	78.31	23.25	39.87	8.20	4.42	12.60	1.86	0.025	862.00	7.28	78.60	0.135	90.085
TiO_2 100mg @6 hrs	78.93	22.43	39.75	7.79	4.70	12.40	1.80	0.024	855.75	6.08	81.39	0.135	88.315
$TiO_2$150mg @6 hrs	81.75	20.75	38.93	7.67	3.90	11.59	1.77	0.021	671.50	5.68	84.11	0.155	84.970
TiO_2 200mg @6 hrs	78.68	18.43	37.25	7.03	4.26	11.36	1.68	0.017	584.00	5.51	84.25	0.175	83.350
ZnO 25mg @6 hrs	89.62	27.18	42.12	9.47	5.40	14.75	2.00	0.027	1025.50	8.99	72.57	0.124	93.965
ZnO 50mg @6 hrs	83.56	25.43	40.75	8.60	4.40	13.37	1.87	0.024	918.50	8.17	74.76	0.125	92.060
ZnO 75mg @6 hrs	82.00	25.81	40.93	7.87	4.43	12.35	1.84	0.024	858.25	7.91	76.16	0.145	89.955
ZnO 100mg @6 hrs	79.12	22.62	39.43	7.65	4.44	12.16	1.83	0.022	681.25	7.28	78.68	0.135	86.995
ZnO 150mg @6 hrs	82.72	22.43	39.75	7.38	4.64	12.17	1.75	0.022	633.25	6.61	82.79	0.156	84.820
ZnO 200mg @6 hrs	80.50	18.31	36.68	7.86	3.89	11.69	1.69	0.017	583.50	5.58	84.98	0.185	82.510
G mean	81.257	22.812	39.812	8.082	4.587	12.718	1.838	0.022	809.076	7.065	78.156	0.141	88.859
SE (d)	0.857	0.586	0.793	0.201	0.109	0.226	0.05	0.728	10.80	0.210	0.987	1.780	0.476
SEM +	0.606	0.415	0.560	0.142	0.077	0.160	0.035	0.515	7.64	0.149	0.698	1.259	0.337
CD @ 5%	1.735	1.187	1.604	0.408	0.222	0.460	0.031	0.004	21.869	0.426	1.998	0.013	0.969
CV	1.49	3.63	2.81	3.53	3.38	2.52	1.29	4.72	1.88	4.21	1.78	5.57	0.76

Note: EC-Electrical conductivity **SME**- Seed metabolic efficiency **FEI**- Field emergence index

4. Conclusion

It is concluded from the present study that the different nano priming treatments showed significant effect on seedling parameters. Tomato seeds primed with T_1 and T_7 i.e. Titanium dioxide (TiO_2) 25 mg and Zinc oxide (ZnO) 25 mg at lower concentrations for 6 hours shows significant result in 5 varieties of tomato for germination, mean germination time, speed of germination, root length, shoot length, seedling length, seedling fresh weight, seedling dry weight, vigour index – I, vigour index –II, electrical conductivity of seed leachates, seed metabolic efficiency, field emergence index followed by T_2 - (50 mg) and T_8 - (75 mg). Among all the priming treatments nano particles at higher concentration showed negative effect on all the seedling parameters in comparison to lower concentrations where as priming treatments at lower concentrations shown positive effect and significance over control. The negative effect of nanoparticles on tomato seedlings at high concentrations is due to the loss of membrane integrity, lipid peroxidation, DNA strand breaks, cell cycle arrest at G2, functional impairments and cellular alterations, damaged root surface cells, shrunk root tip and epidermis, cortical cells become highly vacuolated and collapsed, induced abnormal defense system, increase in the release of ionic salts may be toxic during early development stages.These conclusions are based on the results of laboratory and field investigation. Nanoparticles (both Titanium Dioxide and Zinc Oxide) at lower concentrations is recommended for seed treatment as they are found to be beneficial in improving the seed quality parameters which ultimately lead to good production.

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