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Soilless system: An approach for hybrid seed production in tomato (*Solanum lycopersicum*)

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ABSTRACT

Soilless agriculture is one of the advanced techniques to cultivate plants without soil, with minimal water and nutrients, and helps in vertical growth of agricultural technology. It is an eco-friendly approach widely used for commercial cultivation of quality vegetables. An experiment was conducted at University of Agricultural Sciences, GKVK, Bengaluru, Karnataka during 2017–19 to evaluate the potentiality and suitability of the hydroponics (M2) and aeroponics (M3) methods over conventional method (M1) for hybrid seed production of tomato (*Solanum lycopersicum* L.). The experiment had 12 treatments comprising 3 methods of production, 2 parental lines (TAG 1F and TAG 2F) and 2 seed treatments (S1: Control and S2: thiram @2g/kg + chlorpyrifos @3g/kg). Hoagland nutrient solution with *p*H 5.5–6.5 was used for soilless systems. The results revealed that, among the parental lines, TAG 1F performed better under all the methods of hybrid seed production. Seed treatment increased the per cent survival rate to the tune of 3.26%. Aeroponics and hydroponics performed better than conventional method. Aeroponics showed significantly higher plant height (140.94 cm), fruit weight (124.54 g), total biomass (106.44 g) and test weight (0.39 g) while, hydroponics showed significantly higher number of fruit/plant (45.84) and SVI (2821). It is inferred that soilless agriculture could be a promising tool for quality and year-round healthy hybrid tomato seed production under protected cultivation.

Keywords: Aeroponics, Hybrid seed production, Hydroponics, Soilless cultivation

Tomato (*Solanum lycopersicum* L.) belongs to the solanaceae family which includes more than 3000 species and occupies the largest area among the vegetables in the world after potato (Knapp 2002). Globally, it is cultivated in an area of 46.16 lakh hectare (ha) with 1279.93 lakh tonnes (t) production. India contributes 7.3% share of world production and it occupies 789 thousand ha (HORTISTAT 2018). But the productivity in India (24.6 t/ha) is much lower compared to other countries, viz. USA (96.8 t/ha), Brazil (71.9 t/ha) and China (59.3 t/ha) (FAOSTAT 2018). Quality seeds being an important component contributing to productivity over 15–20%, but without an unwavering supply of high-quality seeds, productivity and quality would decline considerably. The hybrid seed production could be carried out through conventional system with the inherent risk of unpredictable climatic factors, lack of fertile soil, recurrent disease and pest could cause yield loss up to 10–15%. Greenhouse seed production with the risk of soil borne diseases. Thus, the influences of abiotic and biotic factors affect the yield and quality of the seeds, affecting the sustainability of commercial seed growers, producers and industry. In this direction, the soilless cultivation system is a valid opportunity to eliminate the above stated problem.

Soilless culture is the technique of growing plants with their roots immersed in the nutrient solution. These systems can be classified according to the techniques employed as hydroponics, aeroponics and aquaponics. Hydroponics is a technology for growing plants in nutrient solutions with or without the use of an artificial medium to provide mechanical support. Aeroponics is the cultivation of plants in an air or mist environment without the use of soil or an aggregate media. It consists of enclosing the roots in a dark chamber and supplying a nutrient solution using mist device. Carter (1942) was the first researcher to study air culture and described a method of growing plants in water mist to facilitate examination of roots. Currently, about 3.5% of the worldwide area for vegetables production adopts soilless agriculture technique based on hydroponic principle or aeroponics (Hickman 2016).

MATERIALS AND METHODS

Plant material: Present study was carried out at University of Agricultural Sciences, GKVK, Bengaluru, Karnataka during 2017–19 in collaboration with BASF Nunhems Pvt. Ltd. Two female lines, viz. TAG 1F and

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TAG 2F with their respective pollen parents,viz. TAG 1M and TAG 2M were collected from BASF Nunhems. The seeds were treated with thiram @2 g/kg + chlorpyrifos @3 g/kg, a set of untreated control were maintained as per treatment details. Seeds were sown on coco-peat in portrays maintained in polyhouse up to 28 days.

Treatment details of the experiment

P- Parental line	S- Seed treatment	M- Hybrid seed production method
P1: TAG 1F (Female) TAG 1M (Male)	S1: Untreated	M1: Conventional method
P2: TAG 2F (Female) TAG 2M (Male)	S2: Treated (thiram @2 g/kg + chlorpyrifos @3g/kg)	M2: Hydroponic method
		M3: Aeroponic method

Hydroponics and aeroponics prototype: For hydroponics, drip system was adopted, where the nutrient solution was absorbed by the medium from the reservoir with the help of a sponge and it was kept in 6.5 inch pot. Drip was connected to each pot with the set timer delivering Hoagland's nutrient solution for 3 h per day (morning-45 min, afternoon-90 min and night-45 m). Aeroponics method comprises enclosures of 450 × 650 × 450 mm polyvinyl chloride boxes, integrated with motors accompanied by the two misters and one timer per box to control the spray rate. An aluminium L angle frame (22 × 40 mm) was fabricated above the box to stake.

Experimental layout

Conventional: The conventional method under open condition had the net plot size of 5.4 × 3.6 m and the gross plot size of 6.4 × 4.5 m. Tomato seedlings were transplanted at a spacing of 0.9 × 0.6 m. At the time of land preparation urea, single super phosphate and muriate of potash were applied to soil as a basal dose of nitrogen, phosphorus and potassium fertilizer as per the recommended package of UAS, Bangalore (100:100:100 NPK/ha). Urea was supplied in three splits, 50% basal (land preparation), 25% each at 30 and 60 DAT. The entire quantity of P and K were applied basally during land preparation.

Hydroponics: Each pot was connected with drip along with the timer for delivering Hoagland's nutrient solution (nutrients in ppm N:210; P:31; K:234; Ca:200; Mg:34; S:64; Fe:2.5; Mn:0.5; Zn:0.1; B:0.5; Cu:0.08; *p*H:5.5–6.5) (Hoagland 1994). Tomato seedlings were transplanted at a spacing of 0.6 × 0.45 m.

Aeroponics*:* The aeroponics were maintained in six chambers with the individual timer and motor. Six plants of 28 days old seedlings were transplanted to each chamber, Hoagland nutrient solution was sprayed to root zone at an interval of 30:180 s, 30:360 s on and off-cycle in the morning and night hours, respectively. 28 days old seedlings were transplanted at a spacing of 0.45 × 0.45 m.

Pollen viability and hybrid seed production: Seeds and pollen grains were collected from BASF Nunhems Pvt. Ltd. The viability of pollen grains was checked before using them for cross-pollination. It was tested using pollen germination media (a liquid culture without agar) consisting of 0.29 M sucrose, 1.27 mM $Ca(NO_3)_2$, 0.16 mM H_3BO_3 and 1 mM KNO_3 at *p*H 5.2 (Murashige and Skoog's 1962). Pollen grains were observed under projection microscope EUROMEX-HOLLAND, Model- CMEX DC 300X with a magnification of 400X. Hand emasculation and pollination were followed to perform crosses. Pollination was carried out for 15 days from the date of flowering in all the treatments. The crossed fruits were labelled with a tag, red ripened fruits were harvested and hybrid seeds were extracted by the fermentation method.

Observation and experimental design: Plant growth parameter, viz. per cent survival of seedlings (Liu *et al.* 2010), plant height (cm), days to flower initiation, total number of fruit/plants, fruit weight (g), seed yield/plant(g), test weight (g), maximum seed length (were observed under Biovisseed image analyser software) and seedling vigour index-I [germination (%) × mean seedling length (cm)] (Abdul-Baki and Anderson 1973)] were recorded. The experimental data were statistically analysed by adopting Completely Randomized Design with Factorial concept (FCRD) as per the procedure outlined by Cochran and Cox (1957) with the Critical difference (CD) values computed at 5% level, wherever F test was significant.

RESULTS AND DISCUSSION

Pollen viability: The pollen stored at -20°C for about 18 days was tested *in-vitro* for pollen viability using pollen germination media. After 90 min incubation in the media, pollen grains were found viable and observation was based on the pollen germination. The pollen grains were kept at 4°C overnight prior to pollination which were then used for crossing of emasculated flowers. Pollen viability is an important criterion which decides the fertilization and efficient seed set in hybrid seed production (Abdul-Baki 1992) (Fig 1A and B).

Effect of different methods on hybrid seed production: 28 days old seedlings were transferred to all the three methods and observed for interaction between the methods. Method of hybrid seed production influenced per cent survival rate. Both M2 and M3 recorded 100 per cent (%) survival rate where all the seedlings tolerated transplanting shock but in M1 (85.4%) survival rate was lower (Fig 2A). Decreased survival rate in conventional agriculture was due to complex interaction of extrinsic and intrinsic factors, *viz.* seedling vigour, transplanting shock, biotic and abiotic stresses etc. These factors influenced conventional agriculture to a greater magnitude compared to soilless system. Significant difference in plant height under aeroponics and hydroponics was noticed compared to conventional system. Plant height indeed increased under hydroponics (39%) and aeroponics (47%) method compared to conventional system at 110 DAT (Table 1). As the plant nutrition was better maintained in soilless culture (Hoagland's) with optimum *p*H of 5.5–6.5 for tomato which enhanced the root growth in turn led to absorption of nutrients more efficiently leading to increased

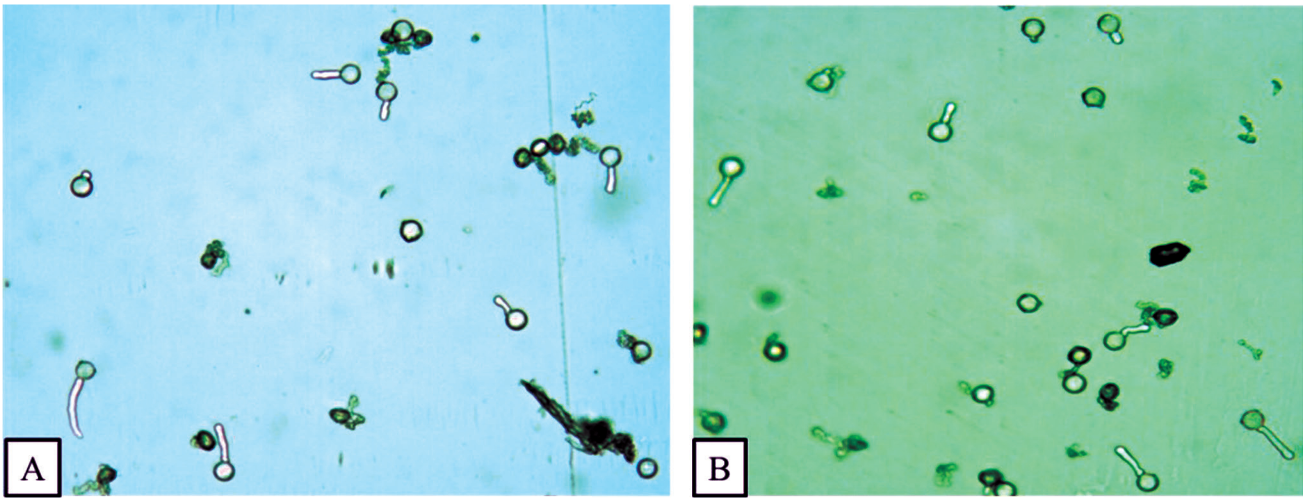

Fig 1 *In-vitro* pollen germination of A) TAG 1M B) TAG 2M.

plant height under soilless system as stated by Hoagland's. There were 4.5 plants/m^2 in aeroponics, 2.8 plants/m^2 in hydroponics and 1.85 plants/m^2 in conventional systems which may be due to high density planting which might encourage the linear growth of plants.

Flowering days was earlier in aeroponics (55.37 days) followed by hydroponics (55.49 days) and late flowering was noticed in conventional system (58.37 days). Total number of fruits/plants has varied significantly among methods of hybrid seed production, M2 (45.84) produced higher fruits/plant followed by M3 (44.60) and lower was noticed in M1 (41.04) (Table 1). Fruit weight was higher in aeroponics (124.54 g) followed by hydroponics (115.66 g) and was lower in conventional system (108.72 g) (Table 2). Higher

Table 1 Influence of methods of hybrid seed production, seed parent and seed treatment on plant height, days to flower initiation and total number of fruit/plants

Treatment		Plant height (ADT)			Plant height (110 DAT)			Days to flower initiation			Total number of fruit/plants		
		P1	P2	Mean	P1	P2	Mean	P1	P2	Mean	P1	P2	Mean
S1	M1	12.38	11.63	12.00	98.27	90.53	94.40	57.63	57.90	57.77	42.33	40.47	41.40
	M2	12.00	10.93	11.47	136.00	131.87	133.93	53.23	56.87	55.05	47.07	44.73	45.90
	M3	11.90	11.05	11.48	141.33	139.00	140.17	53.10	56.53	54.82	46.93	43.00	44.97
S2	M1	13.01	12.11	12.56	99.07	95.73	97.40	56.07	58.80	57.43	41.67	39.70	40.68
	M2	12.92	12.00	12.46	134.17	131.27	132.72	53.73	58.13	55.93	44.93	46.63	45.78
	M3	12.83	12.18	12.51	142.61	140.80	141.70	54.50	57.33	55.92	43.97	44.50	44.23
	Mean	12.51	11.65		125.24	121.53		54.71	57.59		44.48	43.17	
P × S	S1	12.09	11.20	11.65	125.20	120.47	122.83	54.66	57.10	55.88	45.44	42.73	44.09
	S2	12.92	12.10	12.51	125.28	122.60	123.94	54.77	58.09	56.43	43.52	43.61	43.57
P × M	M1	12.70	11.87	12.28	98.67	93.13	95.90	56.85	58.35	57.60	42.00	40.08	41.04
	M2	12.46	11.47	11.96	135.08	131.57	133.33	53.48	57.50	55.49	46.00	45.68	45.84
	M3	12.37	11.62	11.99	141.97	139.90	140.94	53.80	56.93	55.37	45.45	43.75	44.60
		S.Em.±	CD (P=0.05)	CV (%)	S.Em.±	CD (P=0.05)	CV (%)	S.Em±	CD (P=0.05)	CV(%)	S.Em.±	CD (P=0.05)	CV(%)
	P	0.06	0.18	2.12	0.67	1.94	2.29	0.19	0.57	1.50	0.61	NS	5.89
	S	0.06	0.18		0.67	NS		0.19	NS		0.61	NS	
	M	0.07	0.22		0.82	2.38		0.24	0.69		0.75	2.18	
	PS	0.09	NS		0.94	NS		0.27	NS		0.86	NS	
	PM	0.10	NS		1.15	NS		0.34	0.98		1.06	NS	
	SM	0.10	NS		1.15	NS		0.34	NS		1.06	NS	
	PSM	0.15	NS		1.63	NS		0.47	NS		1.49	NS	

Treatment details given in Materials and Methods.

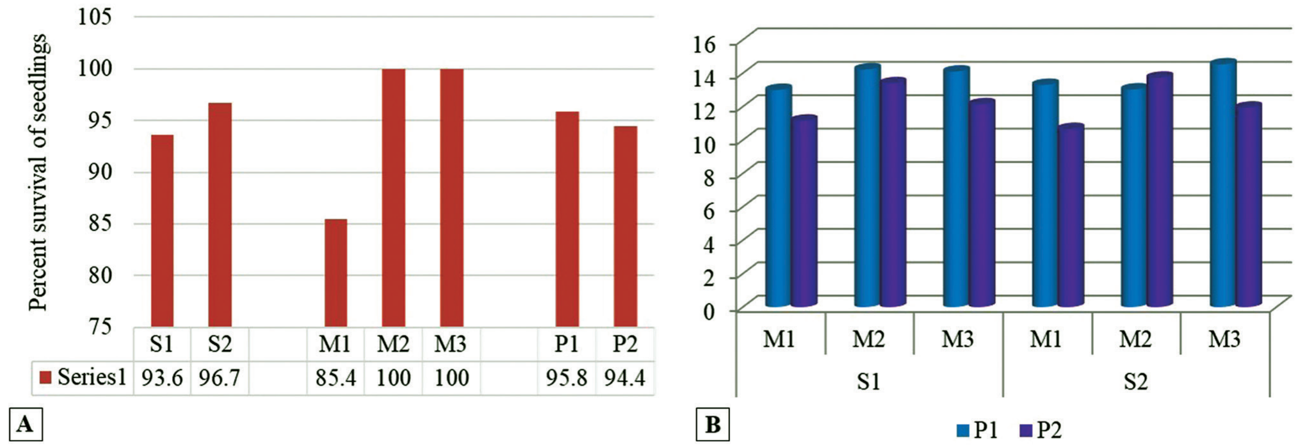

Fig 2 A) Per cent survival of seedlings; B) Seed yield/plant as influenced by different methods of hybrid seed production, parental line and seed treatment in tomato. Treatment details given in Materials and Methods.

seed yield/plant was produced in hydroponics (13.60 g), which was at par with aeroponics (13.18 g) and lower was observed in conventional method (12.03 g) (Fig 2B). Aeroponics (0.39 g) recorded higher test weight which was at par with hydroponics (0.38 g) and lower was recorded in conventional system (0.34 g). Seedling vigour Index-I was higher in hydroponics (2821) followed by aeroponics (2735) and lower was recorded in conventional system (2577). Maximum seed length was analysed under Biovis PSM seed image analyzer. The maximum seed length was observed in aeroponics (0.78 cm), which was at par with hydroponics (0.77 cm) and minimum was observed in conventional system (0.57 cm) (Table 2).

Aeroponics and hydroponics recorded early flowering, significantly higher fruit weight, total fruit number/plant, test weight and SVI-I (Tables 1 and 2). Maboko *et al.* (2008)

Table 2 Quality parameters as influenced by different methods of hybrid seed production, seed parent and seed treatment in tomato

Treatment		Fruit weight (g)			Test weight (g)			Seedling vigour index-I			Maximum seed length (cm)		
		P1	P2	Mean	P1	P2	Mean	P1	P2	Mean	P1	P2	Mean
S1	M1	111.35	102.55	106.95	0.38	0.31	0.34	2549	2517	2533	0.59	0.54	0.57
	M2	120.27	116.43	118.35	0.40	0.37	0.39	2863	2714	2788	0.74	0.80	0.77
	M3	134.81	121.61	128.21	0.40	0.36	0.38	2801	2590	2695	0.80	0.76	0.78
S2	M1	118.57	102.4	110.48	0.38	0.30	0.34	2646	2595	2620	0.58	0.57	0.58
	M2	122.33	103.6	112.97	0.40	0.37	0.38	2831	2874	2853	0.78	0.77	0.77
	M3	125.95	115.77	120.86	0.43	0.38	0.41	2717	2832	2774	0.80	0.77	0.79
	Mean	122.21	110.39		0.39	0.35		2734	2687		0.72	0.70	
P × S	S1	122.14	113.53	117.84	0.39	0.35	0.37	2738	2607	2672	0.71	0.70	0.71
	S2	122.28	107.26	114.77	0.39	0.35	0.38	2731	2767	2749	0.72	0.71	0.71
P × M	M1	114.96	102.47	108.72	0.38	0.30	0.34	2597	2556	2577	0.59	0.56	0.57
	M2	121.3	110.02	115.66	0.40	0.37	0.38	2847	2794	2821	0.76	0.78	0.77
	M3	130.38	118.69	124.54	0.41	0.37	0.39	2759	2711	2735	0.80	0.77	0.78
		S.Em.±	CD (P=0.05)	CV (%)	S.Em.±	CD (P=0.05)	CV (%)	S.Em.±	CD (P=0.05)	CV (%)	S.Em.±	CD (P=0.05)	CV (%)
	P	2.58	7.54		0.0027	0.0079	3.07	31.57	NS	4.94	0.01	NS	7.90
	S	2.58	NS	9.40	0.0027	NS		31.57	NS		0.01	NS	
	M	3.16	9.23		0.0033	0.0097		38.67	112.87		0.02	0.05	
	PS	3.65	NS		0.0038	NS		44.65	NS		0.02	NS	
	PM	4.47	NS		0.0047	0.0112		54.69	NS		0.02	NS	
	SM	4.47	NS		0.0047	0.0137		54.69	NS		0.02	NS	
	PSM	6.33	NS		0.0066	NS		77.34	NS		0.03	NS	

Treatment details given in Materials and Methods.

compared the soil and soilless system and the findings revealed faster and higher total yield of tomato in soilless system. It appears that in controlled conditions with the precise nutrition, *p*H, root-zone aeration and temperature, provides basis for a more favourable sink/source balance which enhanced the better root-shoot growth compared to the complexities of mineralization, mobilization and uptake by plants in conventional system. Thus, the plant and fruit quality parameters increased linearly under soilless system. Further, under controlled soilless conditions, the environmental stress were minimal asides to that of conventional system, thus all-inclusive photosynthates can be utilized for plant growth and quality seed production process hence, soilless system could be an alternative for high quality vegetable seed production specially for hybrids (Gruda 2009, Savvas *et al.* 2013, Liu *et al.* 2016).

Effect of seed treatment on hybrid seed production: Seed treatment significantly affected the per cent survival rate and plant height. Per cent survival rate was higher for seed treatment (96.7%) compared to control seedlings (93.6%) (Fig 2A). Seed treatment improved plant height significantly from the day of transplanting till 110 DAT (12.51 cm to 123.94 cm) compared to untreated control (18.28 cm to 122.83 cm) (Table 1). Seed treatment with thiram and chlorpyriphos increased tomato seedling vigour due to its persistent effect in soil by protecting against the seed/soil borne, insect and pathogens compared to untreated seeds which enhanced the survival rate.

Effect of parental line on hybrid seed production: Genotypic difference among parental line significantly influenced plant height, days to flower initiation, test weight and seed yield/plant. Early flower initiation was observed in TAG 1 (55 days) than TAG 2 (58 days) parental line. TAG 1 recorded the higher fruit weight (122.21 g) followed by TAG 2 (110.39 g) (Table 1). P1 (0.39 g) had the higher test weight compared to P2 (0.35 g) (Table 2) and P1 recorded higher (13.7 g) hybrid seed yield/plant compared to P2 (12.17 g) (Fig 2B). The genetic make-up along with environment interaction will determine the phenotype i.e. plant height, flowering period and seeds/fruit is totally determined by genes and its interaction with the environment. Genotypic difference has been in use since very long time to differentiate the cultivars (Mateus-Rodriguez *et al.* 2014, Kanneh *et al.* 2017, Kaur *et al.* 2017).

Seed is a vital input and resource for food and industrial production and a basic form of conserving plant genetic resources. All farmers small, marginal or large scale, irrespective of farming practices traditional, ecological or conventional, are united by their requirement of seeds as plant propagules. Seed quality is a critical aspect in agriculture to ensure food security. It is affected by number of complex genetic and environmental factors. An attempt was made to check the feasibility of soilless method for hybrid seed production of tomato. Based on the result of the experiment it is concluded that hydroponics and aeroponics cultivation with Hoagland's nutrient media at 5.5–6.4 *p*H can be recommended for hybrid seed production of tomato. There was no significant difference among the soilless methods but seed yield and quality was significantly greater than conventional method. It increased plant height to the tune of 47%, also significantly increased the per cent survival of seedlings, fruit weight, fruit yield, seed yield and seed vigour. As stated by Rajatha *et al.*(2021) the benefit to cost ratio was found higher in aeroponics (2.08) followed by hydroponics (1.97) and lower under the conventional method (1.87) for hybrid seed production of tomato. Hence, soilless system could be a promising tool for quality and healthy hybrid seed production throughout the year under protected cultivation. In near future, it opens new research area for seed production in soilless system.

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