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Study of different seed extraction methods and seed quality parameters in tomato (*Solanum lycopersicum* L.)

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Abstract
This study was conducted at the Seed Science and Technology Laboratory, C.P. College of Agriculture, SDAU to evaluate the effect of different fruit maturity stages and seed extraction methods on tomato seed quality. The experiment used the Kashi Amrit tomato variety and included three stages of fruit maturity (turning red, red and dark red) along with 16 seed extraction methods. The treatments were tested in a Completely Randomized Design (CRD) with factorial concept and three replications. Observations were recorded at three stages: initial, after 3 months and after 6 months of storage. Results showed that seeds extracted from fruits at the dark red stage using 2% HCl solution for 60 minutes had the best performance in terms of seed recovery (%), 1000 seed weight (g), first count (%), germination (%), shoot length (cm), root length (cm), seedling length (cm), fresh shoot weight (mg), fresh root weight (mg), fresh seedling weight (mg), seedling dry weight (mg), seedling vigour index I, seedling vigour index II and storability. If harvesting dark red fruits is not possible due to environmental or labor constraints, red fruits with the same method can be a good alternative. This study helps identify practical methods for obtaining high-quality tomato seeds.

Keywords: Tomato, fruit maturity, seed extraction, seed quality parameters and storage

Introduction
Tomato is one of the most popular vegetables grown worldwide and is rich in nutrients like vitamins, minerals and antioxidants. It is commonly used in fresh form and also processed into products like sauce, ketchup and pickles. The red pigment in Tomato (lycopene) is now being considered as the "world's most powerful natural antioxidant" (Jones, 1916) [5].
Tomato is an important crop in Indian agriculture. The success of the crop largely depends on the quality of seeds used. Good quality seeds should be healthy, free from diseases and able to grow into strong seedlings. Since tomato plants produce fruits over a long time, the stage at which the fruit is harvested affects the seed quality.
Seed quality plays a key role in germination, plant growth and crop yield. Good quality seeds are viable, healthy, pure and capable of producing strong seedlings. In tomato, seed quality is influenced by fruit maturity, extraction method, fermentation time and processing temperature. Since tomato seeds are covered with a sticky gel that can reduce germination, proper extraction is needed to remove the pulp and coating for better seed performance (Muniyappa and Vishwanath, 2006) [7].
Tomato seeds are covered with a sticky gel that prevents germination. So, the extraction process must remove both the pulp and this gel. Common methods include manual removal, fermentation or acid treatment. Fermentation is simple and cheap but can cause seeds to sprout if delayed. Acid methods are faster but need careful handling. Poor extraction methods can damage seeds or spread diseases (Demir and Samit, 2001; Franca *et al.*, 2013) [3, 4]. Also, little information is available about how different methods affect seed performance over storage time. Therefore, this study was carried out to evaluate different seed extraction methods and fruit maturity stages in tomato and their effects on seed quality, both immediately and after storage.

Materials and Methods
Different seed extraction treatments were carried under laboratory conditions in a CRD design with factorial concept and 3 replications was used during *rabi* 2023-24.

The Laboratory experiment was conducted at Centre for Vegetable Research, Department of Genetics and Plant Breeding,
S. D. Agricultural University, Sardarkrushinagar and laboratory of Seed Science and Technology, C. P. College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar.

Treatment Details

Maturity stages

M_1: Harvesting of Tomatoes at Turning Red color
M_2: Harvesting of Tomatoes at Red color
M_3: Harvesting of Tomatoes at Dark Red color

Seed extraction methods

E_1 – Manual extraction method
E_2 – 10 ml 2% HCl /kg slurry for 30 min.
E_3 – 10 ml 2% HCl /kg slurry for 60 min.
E_4 – 10 ml 2% HCl /kg slurry for 90 min.
E_5 – 10 ml 3% HCl /kg slurry for 30 min.
E_6 – 10 ml 3% HCl /kg slurry for 60 min.
E_7 – 10 ml 3% HCl /kg slurry for 90 min.
E_8 – 10 ml 2% H_2SO_4 /kg slurry for 30 min.
E_9 – 10 ml 2% H_2SO_4 /kg slurry for 60 min.
E_{10} – 10 ml 2% H_2SO_4 /kg slurry for 90 min.
E_{11} – 10 ml 3% H_2SO_4 /kg slurry for 30 min.
E_{12} – 10 ml 3% H_2SO_4 /kg slurry for 60 min.
E_{13} – 10 ml 3% H_2SO_4 /kg slurry for 90 min.
E_{14} – Fermentation for 24 hrs.
E_{15} – Fermentation for 48 hrs.
E_{16} – Fermentation for 72 hrs.

This resulted in 48 treatment combinations (3 maturity stages × 16 extraction methods).

Observation to be recorded

1. **Seed recovery (%):** The seed recovery percentage were obtained by dividing the total weight of seed with total fruit weight and multiplied by hundred.
2. **1000 seed weight (g):** The 1000 seed weight in grams was recorded from each treatment as per the procedure given by ISTA (Anon. 2007).
3. **First count (%):** The number of normal seedlings emerged up to 5th day were recorded after keeping the seeds for germination by Between paper method.
4. **Germination (%):** The germination test was done using the "Between Paper Method" as per ISTA (Anon. 2007) rules. From each treatment, 100 freshly harvested seeds were randomly taken in three replications and placed on moist germination paper. Two layers of paper were moistened first; seeds were placed and then covered with a third moist paper sheet.
5. **Shoot length (cm):** Shoot length was measured from the cotyledon to the shoot tip in 10 normal seedlings on the 14th day and the average was recorded in centimeters.
6. **Root length (cm):** The same 10 seedlings were used to measure root length from the cotyledon to the root tip on the 14th day and the average was noted in centimeters.
7. **Seedling length:** Seedling length obtained from sum of shoot length and root length.
8. **Fresh shoot weight (mg):** The shoots of ten seedlings were cut from a nursery tray using a clipper and their weight was measured in milligrams using an electronic balance.
9. **Fresh root weight (mg):** The roots of ten seedlings were cut from a nursery tray using a clipper and their weight was measured in milligrams using an electronic balance.
10. **Seedling fresh weight (mg):** The same ten seedling used for measuring shoot length and root length were weighted using electronic balance and weight was noted in milligram.
11. **Seedling dry weight (mg):** The same ten seedlings used for shoot and root length were placed in a butter paper bag and dried in a hot air oven at 85 ± 2°C for 24 hours. After drying, their weight was measured using an electronic balance and the average dry weight was recorded in milligrams.
12. **Seedling vigour index I:** The vigour index value was calculated as per formula and expressed in number.

Vigour index I = Germination (%) × seedling length (cm)

13. **Seedling vigour index II:** The vigour index value was calculated as per formula and expressed in number.

Vigour index II = Germination (%) × seedling dry weight (mg)

Results

Seed extraction means removing seeds from the fruits and it's a careful process. Even a small mistake during extraction can harm the seed's quality, reduce its strength or affect how it looks. If not done properly, seeds might even start sprouting inside the fruit. In tomatoes, seeds have a slippery, jelly-like coating around them. To clean them, the fruits are first crushed by hand or machine and then the gel is removed using fermentation, chemicals or machines as part of the seed processing steps.

Effect of maturity stages

In this study, seeds taken from fruits harvested at the dark red stage (M_3) showed the best results. They gave the highest seed recovery (0.65%), 1000 seed weight (3.77 g) and strong seed quality traits like high germination (88.25%), first count (81.75%) and good seedling growth. These included longer shoot (7.63 cm), root (4.44 cm) and total seedling length (12.06 cm), along with higher fresh shoot weight (288.94 mg), fresh root weight (123.71 mg), fresh seedling weight (412.65 mg), seedling dry weight (14.72 mg), seedling vigour index I (1070.62) and seedling vigour index II (1317.14). These results were consistent at the time of storage, after three months and even after six months. These results were also supported by the findings of by Takac *et al.* (2014) and Ravat (2018) [11] in brinjal; Kumar (2000) [6], Singh (2002) [13], Nakrani (2021) [8] and Botey *et al.* (2022) [2] in tomato.

Good results were also seen in fruits harvested at the red stage (M_2) with germination of 75.98%, shoot length of 6.78 cm, root length of 4.09 cm and total seedling length of 10.87 cm. It also showed good fresh shoot weight (270.58 mg) and root weight (112.29 mg), seedling dry weight (13.56 mg) and strong vigour index values (Vigour Index I - 835.23 and Vigour Index II - 1052.03). These values remained consistent at the time of storage, after three months and six months (Table 1, Table 2 and Table 3).

Table 1: Effects of fruit maturity stage on seed quality parameters in Tomato at the time of seed extraction

Maturity stage	Seed recovery (%)	1000 seed weight (g)	First count (%)	Germination (%)	Shoot length (cm)	Root length (cm)	Seedling length (cm)
M_1	0.61	2.80	54.19	61.69	4.98	3.50	8.48
M_2	0.63	3.08	69.27	75.98	6.78	4.09	10.87
M_3	0.65	3.77	81.75	88.25	7.63	4.44	12.06
S.Em. ±	0.004	0.006	0.139	0.193	0.014	0.011	0.019
C.D. at 5%	0.011	0.016	0.389	0.542	0.040	0.031	0.052

Maturity stage	Fresh shoot weight (mg)	Fresh root weight (mg)	Seedling fresh weight (mg)	Seedling dry weight (mg)	Seedling vigour index I	Seedling vigour index II
M_1	243.46	103.58	347.04	12.86	531.91	805.78
M_2	270.58	112.29	382.88	13.56	835.23	1052.03
M_3	288.94	123.71	412.65	14.72	1070.62	1317.14
S.Em. ±	0.713	0.345	0.856	0.062	2.951	6.806
C.D. at 5%	2.003	0.967	2.403	0.175	8.284	19.105

Table 2: Effects of fruit maturity stage on seed quality parameters in Tomato 3 months after storage

Maturity stage	1000 seed weight (g)	First count (%)	Germination (%)	Shoot length (cm)	Root length (cm)	Seedling length (cm)
M_1	2.75	52.69	59.67	4.84	3.30	8.14
M_2	3.05	67.29	75.40	6.46	3.79	10.25
M_3	3.74	79.44	87.42	7.41	4.15	11.56
S.Em. ±	0.007	0.142	0.195	0.017	0.014	0.024
C.D. at 5%	0.018	0.400	0.549	0.046	0.039	0.067

Maturity stage	Fresh shoot weight (mg)	Fresh root weight (mg)	Seedling fresh weight (mg)	Seedling dry weight (mg)	Seedling vigour index I	Seedling vigour index II
M_1	228.27	97.17	325.44	12.79	497.68	779.15
M_2	260.35	109.21	369.56	13.47	782.25	1036.09
M_3	277.33	115.40	392.73	14.47	1016.96	1281.80
S.Em. ±	0.840	0.306	1.037	0.058	2.611	5.851
C.D. at 5%	2.359	0.860	2.912	0.163	7.330	16.424

Table 3: Effects of fruit maturity stage on seed quality parameters in Tomato 6 months after storage

Maturity stage	1000 seed weight (g)	First count (%)	Germination (%)	Shoot length (cm)	Root length (cm)	Seedling length (cm)
M_1	2.69	50.94	59.19	4.50	3.20	7.70
M_2	2.98	65.21	74.04	6.42	3.56	9.98
M_3	3.66	77.63	87.02	7.33	3.88	11.21
S.Em. ±	0.007	0.156	0.202	0.019	0.014	0.025
C.D. at 5%	0.020	0.438	0.567	0.052	0.041	0.071

Maturity stage	Fresh shoot weight (mg)	Fresh root weight (mg)	Seedling fresh weight (mg)	Seedling dry weight (mg)	Seedling vigour index I	Seedling vigour index II
M_1	218.35	92.85	311.21	12.71	467.44	767.28
M_2	243.75	104.69	348.44	13.31	749.05	1005.64
M_3	262.69	111.67	374.35	14.20	981.71	1250.52
S.Em. ±	0.924	0.272	1.006	0.055	2.757	4.594
C.D. at 5%	2.594	0.764	2.824	0.154	7.738	12.869

Effect of seed extraction methods

Among the sixteen different seed extraction methods tested, the treatment E_3 (using 10 ml of 2% HCl per kg of slurry for 60 minutes) gave the best overall results at the time of storage, as well as after three and six months of storage. This method recorded the highest seed recovery (0.79%), 1000 seed weight (4.06 g), first count (79.44%) and germination (87.22%). It also showed excellent seedling growth with shoot length of 7.66 cm, root length of 4.82 cm and total seedling length of 12.48 cm. The fresh shoot weight (435.22 mg), fresh root weight (184.89 mg) and total fresh seedling weight (620.11 mg) were also maximum in this treatment. In addition, the seedling dry weight was 19.14 mg, while seedling vigour index I and II were 1100.26 and 1683.33, respectively. The similar results were also reported by Raval *et al.* (2016) [10], Sachan *et al.* (2009) [12] Nakrani (2021) [8] and Pozhilarasi *et al.* (2022) [9] in tomato.

Table 4: Effects of different seed extraction methods on seed quality parameters in Tomato at the time of seed extraction

Extraction method	Seed recovery (%)	1000 seed weight (g)	First count (%)	Germination (%)	Shoot length (cm)	Root length (cm)	Seedling length (cm)
E_1	0.51	2.68	57.00	65.00	5.56	3.14	8.70
E_2	0.70	3.56	75.33	81.56	6.91	4.49	11.40
E_3	0.79	4.06	79.44	87.22	7.66	4.82	12.48
E_4	0.76	4.03	78.67	86.67	7.59	4.78	12.37
E_5	0.71	3.66	76.11	82.78	7.12	4.64	11.77
E_6	0.69	3.39	74.33	80.22	6.77	4.38	11.14
E_7	0.64	3.19	69.00	75.44	6.52	4.08	10.60
E_8	0.56	2.89	62.11	69.22	5.99	3.69	9.68
E_9	0.60	3.05	66.33	72.22	6.30	3.86	10.16
E_{10}	0.54	2.74	61.11	68.67	5.76	3.54	9.30
E_{11}	0.59	3.03	62.89	71.22	6.17	3.70	9.87
E_{12}	0.65	3.31	71.00	76.89	6.59	4.22	10.81
E_{13}	0.53	2.73	60.89	67.89	5.69	3.31	9.00
E_{14}	0.63	3.10	68.11	74.00	6.43	3.98	10.41
E_{15}	0.67	3.35	72.67	79.11	6.71	4.33	11.04
E_{16}	0.52	2.70	59.44	66.78	5.64	3.20	8.84
S.Em. ±	0.009	0.013	0.320	0.446	0.033	0.026	0.043
C.D. at 5%	0.025	0.036	0.899	1.253	0.091	0.072	0.121

Extraction method	Fresh shoot weight (mg)	Fresh root weight (mg)	Seedling fresh weight (mg)	Seedling dry weight (mg)	Seedling vigour index I	Seedling vigour index II
E_1	155.33	70.22	225.56	11.02	585.08	719.25
E_2	320.78	136.56	457.33	16.50	944.64	1359.13
E_3	435.22	184.89	620.11	19.14	1100.26	1683.33
E_4	432.44	183.00	615.44	18.88	1083.28	1648.63
E_5	335.00	142.89	477.89	17.02	989.17	1420.78
E_6	302.67	126.44	429.11	14.91	909.70	1213.30
E_7	271.44	113.33	384.78	12.91	816.39	983.28
E_8	203.44	85.33	288.78	11.70	686.10	814.06
E_9	233.67	97.22	330.89	12.01	750.63	873.58
E_{10}	192.33	80.67	273.00	11.46	654.30	789.41
E_{11}	214.00	91.56	305.56	11.78	720.47	843.18
E_{12}	285.78	119.33	405.11	13.54	847.48	1052.84
E_{13}	183.78	77.78	261.56	11.29	627.40	768.64
E_{14}	248.00	104.56	352.56	12.27	788.30	913.75
E_{15}	293.78	122.67	416.44	13.76	890.53	1100.47
E_{16}	174.89	74.67	249.56	11.19	607.69	749.39
S.Em. ±	1.648	0.796	1.977	0.144	6.815	15.717
C.D. at 5%	4.625	2.234	5.549	0.404	19.131	44.120

Table 5: Effects of different seed extraction methods on seed quality parameters in Tomato 3 months after storage

Extraction method	1000 seed weight (g)	First count (%)	Germination (%)	Shoot length (cm)	Root length (cm)	Seedling length (cm)
E_1	2.63	55.56	63.89	5.29	2.79	8.08
E_2	3.54	73.67	80.56	6.81	4.29	11.10
E_3	4.03	77.78	86.78	7.47	4.67	12.13
E_4	4.00	76.89	86.33	7.39	4.61	12.00
E_5	3.64	74.67	82.22	7.06	4.32	11.38
E_6	3.37	72.00	79.33	6.68	4.17	10.84
E_7	3.16	66.89	74.89	6.26	3.91	10.17
E_8	2.85	60.89	66.78	5.63	3.27	8.90
E_9	3.02	64.78	72.22	5.94	3.63	9.58
E_{10}	2.69	59.33	66.11	5.52	3.11	8.63
E_{11}	2.99	61.22	69.78	5.78	3.41	9.19
E_{12}	3.29	68.67	76.22	6.37	3.97	10.33
E_{13}	2.67	58.44	65.22	5.48	2.98	8.46
E_{14}	3.06	65.56	73.00	6.00	3.81	9.81
E_{15}	3.33	70.67	78.56	6.62	4.12	10.74
E_{16}	2.64	56.56	64.67	5.44	2.90	8.34
S.Em. ±	0.015	0.329	0.451	0.037	0.032	0.055
C.D. at 5%	0.043	0.923	1.267	0.107	0.091	0.154

Extraction method	Fresh shoot weight (mg)	Fresh root weight (mg)	Seedling fresh weight (mg)	Seedling dry weight (mg)	Seedling vigour index I	Seedling vigour index II
E_1	143.56	59.22	202.78	10.95	535.98	703.06
E_2	307.00	134.44	441.44	16.44	908.19	1336.48
E_3	414.67	172.67	587.33	18.46	1062.83	1609.56
E_4	412.11	171.11	583.22	18.35	1046.39	1591.14
E_5	326.56	140.89	467.44	16.95	949.17	1404.97
E_6	294.33	122.33	416.67	14.84	874.69	1194.78
E_7	259.33	109.00	368.33	12.84	776.06	970.94
E_8	194.22	82.33	276.56	11.63	614.84	781.57
E_9	215.89	90.67	306.56	11.95	707.54	868.65
E_{10}	183.11	74.78	257.89	11.40	590.44	756.32
E_{11}	202.56	83.67	286.22	11.71	659.94	821.62
E_{12}	274.33	116.67	391.00	13.47	802.87	1038.24
E_{13}	177.67	75.11	252.78	11.22	570.83	734.77
E_{14}	232.67	97.67	330.33	12.20	732.21	896.16
E_{15}	279.33	115.44	394.78	13.69	859.38	1087.41
E_{16}	167.78	70.11	237.89	11.12	558.71	721.90
S.Em. ±	1.940	0.707	2.396	0.134	6.030	13.512
C.D. at 5%	5.447	1.985	6.725	0.377	16.929	37.930

Table 6: Effects of different seed extraction methods on seed quality parameters in Tomato 6 months after storage

Extraction method	1000 seed weight (g)	First count (%)	Germination (%)	Shoot length (cm)	Root length (cm)	Seedling length (cm)
E_1	2.58	53.78	62.89	5.14	2.61	7.76
E_2	3.46	71.56	79.44	6.57	4.09	10.66
E_3	3.95	75.89	86.11	7.41	4.42	11.83
E_4	3.92	75.00	85.56	7.36	4.37	11.72
E_5	3.56	72.11	81.56	6.72	4.16	10.88
E_6	3.29	70.33	78.89	6.40	4.00	10.40
E_7	3.08	65.33	74.44	6.08	3.77	9.84
E_8	2.78	58.00	66.00	5.56	2.99	8.54
E_9	2.95	63.22	71.78	5.89	3.44	9.33
E_{10}	2.63	57.33	65.11	5.44	2.90	8.34
E_{11}	2.92	59.56	68.00	5.69	3.26	8.94
E_{12}	3.20	66.89	75.89	6.17	3.81	9.98
E_{13}	2.62	56.56	64.44	5.37	2.73	8.10
E_{14}	2.99	64.33	72.67	6.01	3.67	9.68
E_{15}	3.24	68.67	78.00	6.23	3.87	10.10
E_{16}	2.59	54.89	63.89	5.28	2.69	7.97
S.Em. ±	0.016	0.360	0.466	0.043	0.033	0.058
C.D. at 5%	0.046	1.011	1.309	0.120	0.094	0.163

Extraction method	Fresh shoot weight (mg)	Fresh root weight (mg)	Seedling fresh weight (mg)	Seedling dry weight (mg)	Seedling vigour index I	Seedling vigour index II
E_1	137.56	58.33	195.89	10.89	507.80	687.98
E_2	298.33	130.11	428.44	16.30	860.16	1305.74
E_3	404.89	169.44	574.33	17.67	1030.51	1523.54
E_4	401.78	167.89	569.67	17.60	1013.83	1508.05
E_5	310.44	133.67	444.11	16.70	898.76	1372.12
E_6	281.44	117.89	399.33	14.77	835.58	1181.80
E_7	249.22	104.33	353.56	12.77	748.40	960.35
E_8	177.44	77.56	255.00	11.57	583.54	768.49
E_9	196.89	83.44	280.33	11.88	687.11	858.55
E_{10}	165.56	71.56	237.11	11.33	563.81	740.55
E_{11}	182.44	78.67	261.11	11.65	627.16	796.48
E_{12}	257.22	108.89	366.11	13.40	773.19	1028.90
E_{13}	157.78	69.67	227.44	11.16	541.27	721.90
E_{14}	224.00	94.89	318.89	12.14	719.64	887.37
E_{15}	267.56	114.89	382.44	13.63	804.12	1074.19
E_{16}	153.00	67.89	220.89	11.06	528.90	708.96
S.Em. ±	2.134	0.629	2.323	0.127	6.366	10.609
C.D. at 5%	5.991	1.764	6.522	0.356	17.870	29.781

Interaction effect of maturity stages and seed extraction methods

Among the 48 combinations of fruit maturity stages and seed extraction methods, the treatment M_3E_3 (fruits harvested at dark red stage and seeds extracted with 10 ml of 2% HCl per kg slurry for 60 minutes) gave the best results. It recorded the highest 1000 seed weight (4.49 g), first count (91.00%), germination (98.00%), shoot length

(8.40 cm), root length (5.20 cm) and seedling length (13.60 cm). It also showed maximum fresh shoot weight (460.33 mg), fresh root weight (198.33 mg), fresh seedling weight (658.67 mg), seedling dry weight (20.95 mg), vigour index I (1332.73) and vigour index II (2052.77). Very good results were also seen in M_3E_4 (dark red fruits with 2% HCl for 90 minutes) and in M_2E_3 (red fruits with 2% HCl for 60 minutes), where germination was 91.67%, shoot length 7.77 cm, root length 5.03 cm, seedling length 12.80 cm, fresh shoot weight 437.67 mg, fresh root weight 183.67 mg, fresh seedling weight 621.33 mg, dry weight 18.77 mg, vigour index I 1173.43 and vigour index II 1721.92. Similar performance was also found in M_2E_4 (red fruits with 2% HCl for 90 minutes). These results were also supported by the findings of by Ravat (2018) [11] in brinjal; Kumar (2000) [6], Singh (2002) [13] and Nakrani (2021) [8] in tomato (Table 7, Table 8 and Table 9).

Table 7: Effects of interaction effects on seed quality parameters in Tomato at the time of seed extraction

Maturity stages (M) × Extraction methods (E)	Seed recovery (%)	1000 seed weight (g)	First count (%)	Germination (%)	Shoot length (cm)	Root length (cm)	Seedling length (cm)
$M_1 \times E_1$	0.48	2.56	41.00	50.00	3.87	2.53	6.40
$M_1 \times E_2$	0.68	2.91	61.33	66.67	5.57	4.07	9.63
$M_1 \times E_3$	0.76	3.58	62.67	72.00	6.80	4.23	11.03
$M_1 \times E_4$	0.75	3.54	62.33	71.67	6.77	4.20	10.97
$M_1 \times E_5$	0.69	3.03	62.00	69.33	5.77	4.13	9.90
$M_1 \times E_6$	0.67	2.91	60.33	66.33	5.20	3.93	9.13
$M_1 \times E_7$	0.62	2.58	55.67	62.67	5.00	3.47	8.74
$M_1 \times E_8$	0.53	2.56	48.67	57.33	4.30	3.33	7.63
$M_1 \times E_9$	0.58	2.56	53.67	58.67	4.67	3.40	8.07
$M_1 \times E_{10}$	0.52	2.56	47.33	56.67	4.10	3.13	7.23
$M_1 \times E_{11}$	0.57	2.56	50.33	58.00	4.53	3.33	7.87
$M_1 \times E_{12}$	0.64	2.82	57.67	63.33	5.10	3.77	8.87
$M_1 \times E_{13}$	0.51	2.56	46.67	55.67	4.07	2.73	6.80
$M_1 \times E_{14}$	0.61	2.56	54.67	60.33	4.80	3.43	8.23
$M_1 \times E_{15}$	0.66	2.89	58.33	64.67	5.13	3.83	8.97
$M_1 \times E_{16}$	0.51	2.56	44.33	53.67	4.00	2.53	6.53
$M_2 \times E_1$	0.51	2.56	57.00	65.33	6.00	3.37	9.37
$M_2 \times E_2$	0.71	3.42	76.67	83.67	7.30	4.50	11.80
$M_2 \times E_3$	0.79	4.10	84.67	91.67	7.77	5.03	12.80
$M_2 \times E_4$	0.77	4.08	83.67	91.00	7.67	4.97	12.63
$M_2 \times E_5$	0.71	3.51	77.67	84.33	7.30	4.67	11.97
$M_2 \times E_6$	0.68	3.18	76.33	82.00	7.27	4.40	11.67
$M_2 \times E_7$	0.63	3.02	68.67	75.33	6.80	4.17	10.97
$M_2 \times E_8$	0.57	2.78	61.33	67.67	6.27	3.63	9.90
$M_2 \times E_9$	0.61	2.92	66.00	72.33	6.57	3.97	10.53
$M_2 \times E_{10}$	0.55	2.56	60.67	67.33	6.17	3.50	9.67
$M_2 \times E_{11}$	0.60	2.90	62.33	70.33	6.37	3.60	9.97
$M_2 \times E_{12}$	0.65	3.07	71.00	76.67	6.87	4.27	11.13
$M_2 \times E_{13}$	0.53	2.56	60.33	66.67	6.10	3.40	9.50
$M_2 \times E_{14}$	0.62	2.97	68.33	74.00	6.80	4.07	10.87
$M_2 \times E_{15}$	0.66	3.10	75.00	81.33	7.20	4.37	11.57
$M_2 \times E_{16}$	0.52	2.56	58.67	66.00	6.07	3.53	9.60
$M_3 \times E_1$	0.53	2.93	73.00	79.67	6.80	3.53	10.33
$M_3 \times E_2$	0.71	4.35	88.00	94.33	7.87	4.90	12.77
$M_3 \times E_3$	0.81	4.49	91.00	98.00	8.40	5.20	13.60
$M_3 \times E_4$	0.78	4.46	90.00	97.33	8.33	5.17	13.50
$M_3 \times E_5$	0.74	4.43	88.67	94.67	8.30	5.13	13.43
$M_3 \times E_6$	0.71	4.09	86.33	92.33	7.83	4.80	12.63
$M_3 \times E_7$	0.66	3.97	82.67	88.33	7.77	4.60	12.37
$M_3 \times E_8$	0.58	3.32	76.33	82.67	7.40	4.10	11.50
$M_3 \times E_9$	0.62	3.68	79.33	85.67	7.67	4.20	11.87
$M_3 \times E_{10}$	0.56	3.08	75.33	82.00	7.00	4.00	11.00
$M_3 \times E_{11}$	0.61	3.63	76.00	85.33	7.60	4.17	11.77
$M_3 \times E_{12}$	0.68	4.03	84.33	90.67	7.80	4.63	12.43
$M_3 \times E_{13}$	0.55	3.06	75.67	81.33	6.90	3.80	10.70
$M_3 \times E_{14}$	0.64	3.76	81.33	87.67	7.70	4.43	12.13
$M_3 \times E_{15}$	0.69	4.07	84.67	91.33	7.80	4.80	12.60
$M_3 \times E_{16}$	0.54	2.97	75.33	80.67	6.87	3.53	10.40
S.Em. ±	0.015	0.022	0.555	0.773	0.056	0.045	0.075
C.D. at 5%	NS	0.063	1.558	2.169	0.158	0.125	0.209

Maturity stages (M) × Extraction methods (E)	Fresh shoot weight (mg)	Fresh root weight (mg)	Seedling fresh weight (mg)	Seedling dry weight (mg)	Seedling vigour index I	Seedling vigour index II
$M_1 \times E_1$	149.33	64.67	214.00	10.69	320.03	534.44
$M_1 \times E_2$	287.33	124.67	412.00	15.05	642.27	1003.56
$M_1 \times E_3$	407.67	172.67	580.33	17.71	794.60	1275.30
$M_1 \times E_4$	404.00	170.67	574.67	17.56	786.03	1257.81
$M_1 \times E_5$	313.00	134.67	447.67	15.41	686.40	1068.57
$M_1 \times E_6$	272.67	114.67	387.33	13.10	605.83	868.86
$M_1 \times E_7$	247.00	103.67	350.67	12.10	530.57	758.00
$M_1 \times E_8$	182.67	77.67	260.33	11.31	437.67	648.52
$M_1 \times E_9$	206.00	86.67	292.67	11.52	473.27	675.84
$M_1 \times E_{10}$	170.67	74.67	245.33	11.21	410.00	635.59
$M_1 \times E_{11}$	192.67	84.67	277.33	11.40	456.23	661.12
$M_1 \times E_{12}$	253.67	106.67	360.33	12.45	561.63	788.79
$M_1 \times E_{13}$	162.67	69.67	232.33	11.02	378.63	613.60
$M_1 \times E_{14}$	219.67	93.67	313.33	11.82	496.90	713.26
$M_1 \times E_{15}$	268.67	111.33	380.00	12.45	579.97	805.00
$M_1 \times E_{16}$	157.67	66.67	224.33	10.88	350.60	584.18
$M_2 \times E_1$	155.33	69.00	224.33	11.12	611.97	726.80
$M_2 \times E_2$	329.67	137.67	467.33	16.60	987.23	1388.92
$M_2 \times E_3$	437.67	183.67	621.33	18.77	1173.43	1721.92
$M_2 \times E_4$	436.67	181.67	618.33	18.54	1149.80	1687.23
$M_2 \times E_5$	339.67	141.67	481.33	17.75	1009.30	1498.50
$M_2 \times E_6$	303.00	125.33	428.33	14.30	956.67	1172.63
$M_2 \times E_7$	277.33	115.00	392.33	12.29	826.20	926.19
$M_2 \times E_8$	202.67	82.00	284.67	11.53	669.90	780.53
$M_2 \times E_9$	236.67	97.00	333.67	11.66	762.07	843.41
$M_2 \times E_{10}$	191.33	77.00	268.33	11.43	650.90	769.70
$M_2 \times E_{11}$	207.33	85.67	293.00	11.61	701.03	816.74
$M_2 \times E_{12}$	288.67	119.00	407.67	13.15	853.50	1008.37
$M_2 \times E_{13}$	188.67	78.33	267.00	11.30	633.27	752.83
$M_2 \times E_{14}$	261.33	107.67	369.00	11.88	804.07	879.36
$M_2 \times E_{15}$	292.67	122.00	414.67	13.70	940.83	1114.87
$M_2 \times E_{16}$	180.67	74.00	254.67	11.28	633.57	744.40
$M_3 \times E_1$	161.33	77.00	238.33	11.25	823.23	896.52
$M_3 \times E_2$	345.33	147.33	492.67	17.86	1204.43	1684.90
$M_3 \times E_3$	460.33	198.33	658.67	20.95	1332.73	2052.77
$M_3 \times E_4$	456.67	196.67	653.33	20.55	1314.00	2000.86
$M_3 \times E_5$	352.33	152.33	504.67	17.90	1271.80	1695.27
$M_3 \times E_6$	332.33	139.33	471.67	17.31	1166.60	1598.41
$M_3 \times E_7$	290.00	121.33	411.33	14.33	1092.40	1265.65
$M_3 \times E_8$	225.00	96.33	321.33	12.25	950.73	1013.13
$M_3 \times E_9$	258.33	108.00	366.33	12.86	1016.57	1101.49
$M_3 \times E_{10}$	215.00	90.33	305.33	11.74	902.00	962.95
$M_3 \times E_{11}$	242.00	104.33	346.33	12.32	1004.13	1051.68
$M_3 \times E_{12}$	315.00	132.33	447.33	15.01	1127.30	1361.34
$M_3 \times E_{13}$	200.00	85.33	285.33	11.55	870.30	939.48
$M_3 \times E_{14}$	263.00	112.33	375.33	13.10	1063.93	1148.64
$M_3 \times E_{15}$	320.00	134.67	454.67	15.12	1150.80	1381.54
$M_3 \times E_{16}$	186.33	83.33	269.67	11.40	838.90	919.60
S.Em. ±	2.854	1.379	3.424	0.249	11.804	27.222
C.D. at 5%	8.011	3.870	9.611	0.700	33.136	76.418

Table 8: Effects of interaction effects on seed quality parameters in Tomato 3 months after storage

Maturity stages (M) × Extraction methods (E)	1000 seed weight (g)	First count (%)	Germination (%)	Shoot length (cm)	Root length (cm)	Seedling length (cm)
$M_1 \times E_1$	2.49	39.67	47.00	3.67	2.40	6.07
$M_1 \times E_2$	2.89	59.67	66.67	5.60	3.83	9.43
$M_1 \times E_3$	3.56	61.67	72.00	6.77	4.20	10.97
$M_1 \times E_4$	3.52	61.00	71.67	6.63	4.17	10.80
$M_1 \times E_5$	3.01	60.33	69.00	5.80	3.90	9.70
$M_1 \times E_6$	2.89	59.33	65.67	5.30	3.70	9.00
$M_1 \times E_7$	2.55	54.67	62.33	4.87	3.43	8.30
$M_1 \times E_8$	2.49	48.67	50.67	4.00	2.77	6.77
$M_1 \times E_9$	2.49	52.33	59.33	4.40	3.10	7.50
$M_1 \times E_{10}$	2.49	46.33	49.67	3.87	2.70	6.57
$M_1 \times E_{11}$	2.49	49.33	55.67	4.20	2.87	7.07
$M_1 \times E_{12}$	2.80	56.00	63.00	4.97	3.53	8.50

$M_1 \times E_{13}$	2.49	44.67	49.00	3.83	2.63	6.47
$M_1 \times E_{14}$	2.49	52.67	60.00	4.47	3.37	7.83
$M_1 \times E_{15}$	2.87	56.33	64.33	5.20	3.63	8.83
$M_1 \times E_{16}$	2.49	40.33	48.67	3.80	2.57	6.37
$M_2 \times E_1$	2.49	56.33	65.67	5.57	2.83	8.40
$M_2 \times E_2$	3.40	76.00	81.67	7.13	4.20	11.33
$M_2 \times E_3$	4.08	83.00	90.33	7.43	4.73	12.17
$M_2 \times E_4$	4.06	81.67	90.00	7.37	4.63	12.00
$M_2 \times E_5$	3.50	76.67	84.00	7.23	4.20	11.43
$M_2 \times E_6$	3.16	72.00	81.33	7.10	4.13	11.23
$M_2 \times E_7$	3.00	66.67	75.00	6.47	3.93	10.40
$M_2 \times E_8$	2.76	59.67	67.67	5.83	3.43	9.27
$M_2 \times E_9$	2.90	64.33	72.00	6.20	3.87	10.07
$M_2 \times E_{10}$	2.51	58.33	67.00	5.73	3.37	9.10
$M_2 \times E_{11}$	2.87	59.67	69.33	6.00	3.50	9.50
$M_2 \times E_{12}$	3.05	68.67	76.00	6.60	3.97	10.57
$M_2 \times E_{13}$	2.49	58.00	66.67	5.70	3.03	8.73
$M_2 \times E_{14}$	2.95	65.67	73.33	6.23	3.80	10.03
$M_2 \times E_{15}$	3.07	72.67	80.67	7.07	4.10	11.17
$M_2 \times E_{16}$	2.49	57.33	66.00	5.67	2.93	8.60
$M_3 \times E_1$	2.91	70.67	79.00	6.63	3.13	9.77
$M_3 \times E_2$	4.33	85.33	93.33	7.70	4.83	12.53
$M_3 \times E_3$	4.44	88.67	98.00	8.20	5.07	13.27
$M_3 \times E_4$	4.41	88.00	97.33	8.17	5.03	13.20
$M_3 \times E_5$	4.41	87.00	93.67	8.13	4.87	13.00
$M_3 \times E_6$	4.06	84.67	91.00	7.63	4.67	12.30
$M_3 \times E_7$	3.94	79.33	87.33	7.43	4.37	11.80
$M_3 \times E_8$	3.29	74.33	82.00	7.07	3.60	10.67
$M_3 \times E_9$	3.66	77.67	85.33	7.23	3.93	11.17
$M_3 \times E_{10}$	3.06	73.33	81.67	6.97	3.27	10.23
$M_3 \times E_{11}$	3.61	74.67	84.33	7.13	3.87	11.00
$M_3 \times E_{12}$	4.01	81.33	89.67	7.53	4.40	11.93
$M_3 \times E_{13}$	3.03	72.67	80.00	6.90	3.27	10.17
$M_3 \times E_{14}$	3.73	78.33	85.67	7.30	4.27	11.57
$M_3 \times E_{15}$	4.04	83.00	90.67	7.60	4.63	12.23
$M_3 \times E_{16}$	2.95	72.00	79.33	6.87	3.20	10.07
S.Em. ±	0.026	0.569	0.782	0.066	0.056	0.095
C.D. at 5%	0.074	1.598	2.194	0.186	0.158	0.266

Maturity stages (M) × Extraction methods (E)	**Fresh shoot weight (mg)**	**Fresh root weight (mg)**	**Seedling fresh weight (mg)**	**Seedling dry weight (mg)**	**Seedling vigour index I**	**Seedling vigour index II**
$M_1 \times E_1$	134.33	55.33	189.67	10.62	285.17	499.18
$M_1 \times E_2$	264.00	130.00	394.00	14.99	628.90	999.36
$M_1 \times E_3$	361.00	152.67	513.67	17.64	789.40	1270.39
$M_1 \times E_4$	358.33	151.00	509.33	17.49	773.90	1253.15
$M_1 \times E_5$	303.00	126.67	429.67	15.34	669.27	1058.75
$M_1 \times E_6$	270.00	114.67	384.67	13.03	591.07	856.23
$M_1 \times E_7$	234.00	99.67	333.67	12.03	517.53	750.14
$M_1 \times E_8$	173.00	73.67	246.67	11.24	342.83	569.67
$M_1 \times E_9$	187.67	77.67	265.33	11.45	444.90	679.34
$M_1 \times E_{10}$	163.00	69.67	232.67	11.15	326.10	553.81
$M_1 \times E_{11}$	182.00	76.67	258.67	11.33	393.43	630.82
$M_1 \times E_{12}$	250.00	103.67	353.67	12.38	535.47	780.31
$M_1 \times E_{13}$	160.00	68.00	228.00	10.95	316.80	536.87
$M_1 \times E_{14}$	204.00	85.67	289.67	11.76	469.97	705.22
$M_1 \times E_{15}$	254.00	105.00	359.00	12.38	568.30	796.65
$M_1 \times E_{16}$	154.00	64.67	218.67	10.82	309.90	526.56
$M_2 \times E_1$	143.00	59.67	202.67	11.06	551.20	726.25
$M_2 \times E_2$	322.00	133.67	455.67	16.53	925.90	1350.17
$M_2 \times E_3$	434.00	181.00	615.00	18.48	1098.97	1669.17
$M_2 \times E_4$	431.67	180.00	611.67	18.39	1076.07	1649.34
$M_2 \times E_5$	330.67	143.67	474.33	17.68	960.60	1484.87
$M_2 \times E_6$	300.00	125.67	425.67	14.24	913.73	1158.25
$M_2 \times E_7$	263.00	111.67	374.67	12.23	780.10	917.16
$M_2 \times E_8$	192.00	80.67	272.67	11.46	627.03	775.73
$M_2 \times E_9$	223.00	95.67	318.67	11.59	724.80	834.72
$M_2 \times E_{10}$	185.33	71.00	256.33	11.36	609.50	761.51
$M_2 \times E_{11}$	199.67	79.67	279.33	11.54	658.67	800.29

$M_2 \times E_{12}$	270.00	120.00	390.00	13.08	803.10	994.13
$M_2 \times E_{13}$	178.00	74.67	252.67	11.23	582.30	748.95
$M_2 \times E_{14}$	243.00	101.67	344.67	11.82	735.77	866.84
$M_2 \times E_{15}$	279.00	116.67	395.67	13.64	900.67	1100.03
$M_2 \times E_{16}$	171.33	72.00	243.33	11.21	567.60	740.08
$M_3 \times E_1$	153.33	62.67	216.00	11.19	771.57	883.75
$M_3 \times E_2$	335.00	139.67	474.67	17.79	1169.77	1659.91
$M_3 \times E_3$	449.00	184.33	633.33	19.28	1300.13	1889.11
$M_3 \times E_4$	446.33	182.33	628.67	19.16	1289.20	1870.94
$M_3 \times E_5$	346.00	152.33	498.33	17.84	1217.63	1671.29
$M_3 \times E_6$	313.00	126.67	439.67	17.25	1119.27	1569.87
$M_3 \times E_7$	281.00	115.67	396.67	14.26	1030.53	1245.52
$M_3 \times E_8$	217.67	92.67	310.33	12.19	874.67	999.31
$M_3 \times E_9$	237.00	98.67	335.67	12.79	952.93	1091.91
$M_3 \times E_{10}$	201.00	83.67	284.67	11.68	835.73	953.64
$M_3 \times E_{11}$	226.00	94.67	320.67	12.26	927.73	1033.74
$M_3 \times E_{12}$	303.00	126.33	429.33	14.95	1070.03	1340.26
$M_3 \times E_{13}$	195.00	82.67	277.67	11.48	813.40	918.50
$M_3 \times E_{14}$	251.00	105.67	356.67	13.03	990.90	1116.40
$M_3 \times E_{15}$	305.00	124.67	429.67	15.06	1109.17	1365.55
$M_3 \times E_{16}$	178.00	73.67	251.67	11.33	798.63	899.05
S.Em. ±	3.361	1.225	4.149	0.233	10.445	23.403
C.D. at 5%	9.435	3.438	11.647	0.653	29.321	65.697

Table 9: Effects of interaction effects on seed quality parameters in Tomato 6 months after storage

Maturity stages (M) × Extraction methods (E)	1000 seed weight (g)	First count (%)	Germination (%)	Shoot length (cm)	Root length (cm)	Seedling length (cm)
$M_1 \times E_1$	2.45	38.00	46.67	3.37	2.30	5.67
$M_1 \times E_2$	2.81	57.67	66.00	5.20	3.80	9.00
$M_1 \times E_3$	3.48	60.33	70.67	6.43	4.07	10.50
$M_1 \times E_4$	3.44	59.67	70.33	6.37	4.07	10.43
$M_1 \times E_5$	2.93	58.33	68.33	5.57	3.87	9.43
$M_1 \times E_6$	2.80	57.33	65.67	4.87	3.60	8.47
$M_1 \times E_7$	2.47	53.67	62.00	4.30	3.43	7.73
$M_1 \times E_8$	2.45	45.33	50.67	3.73	2.60	6.33
$M_1 \times E_9$	2.45	51.00	59.33	4.07	3.00	7.07
$M_1 \times E_{10}$	2.45	44.67	49.00	3.63	2.53	6.17
$M_1 \times E_{11}$	2.45	45.67	54.67	4.00	2.80	6.80
$M_1 \times E_{12}$	2.72	54.00	63.00	4.50	3.43	7.93
$M_1 \times E_{13}$	2.45	43.33	48.67	3.63	2.47	6.10
$M_1 \times E_{14}$	2.45	51.67	60.00	4.33	3.27	7.60
$M_1 \times E_{15}$	2.78	54.67	64.00	4.53	3.53	8.07
$M_1 \times E_{16}$	2.45	39.67	48.00	3.43	2.43	5.87
$M_2 \times E_1$	2.45	53.67	63.67	5.47	2.67	8.13
$M_2 \times E_2$	3.32	74.33	80.67	6.80	4.00	10.80
$M_2 \times E_3$	4.00	81.33	89.67	7.60	4.47	12.07
$M_2 \times E_4$	3.97	80.33	89.00	7.57	4.40	11.97
$M_2 \times E_5$	3.41	74.67	83.33	6.87	4.10	10.97
$M_2 \times E_6$	3.08	71.33	80.33	6.73	3.97	10.70
$M_2 \times E_7$	2.91	65.00	74.33	6.60	3.73	10.33
$M_2 \times E_8$	2.68	56.67	65.33	5.93	3.23	9.17
$M_2 \times E_9$	2.82	62.00	71.00	6.40	3.40	9.80
$M_2 \times E_{10}$	2.45	56.00	65.00	5.83	3.07	8.90
$M_2 \times E_{11}$	2.79	57.00	66.33	6.00	3.17	9.17
$M_2 \times E_{12}$	2.97	66.67	75.00	6.63	3.80	10.43
$M_2 \times E_{13}$	2.45	55.33	64.67	5.63	2.80	8.43
$M_2 \times E_{14}$	2.87	64.33	72.33	6.40	3.60	10.00
$M_2 \times E_{15}$	2.99	70.00	80.00	6.63	3.83	10.47
$M_2 \times E_{16}$	2.45	54.67	64.00	5.67	2.73	8.40
$M_3 \times E_1$	2.83	69.67	78.33	6.60	2.87	9.47
$M_3 \times E_2$	4.24	82.67	91.67	7.70	4.47	12.17
$M_3 \times E_3$	4.37	86.00	98.00	8.20	4.73	12.93
$M_3 \times E_4$	4.34	85.00	97.33	8.13	4.63	12.77
$M_3 \times E_5$	4.33	83.33	93.00	7.73	4.50	12.23
$M_3 \times E_6$	3.98	82.33	90.67	7.60	4.43	12.03
$M_3 \times E_7$	3.86	77.33	87.00	7.33	4.13	11.47
$M_3 \times E_8$	3.21	72.00	82.00	7.00	3.13	10.13
$M_3 \times E_9$	3.58	76.67	85.00	7.20	3.93	11.13

$M_3 \times E_{10}$	2.98	71.33	81.33	6.87	3.10	9.97
$M_3 \times E_{11}$	3.53	76.00	83.00	7.07	3.80	10.87
$M_3 \times E_{12}$	3.93	80.00	89.67	7.37	4.20	11.57
$M_3 \times E_{13}$	2.95	71.00	80.00	6.83	2.93	9.77
$M_3 \times E_{14}$	3.65	77.00	85.67	7.30	4.13	11.43
$M_3 \times E_{15}$	3.96	81.33	90.00	7.53	4.23	11.77
$M_3 \times E_{16}$	2.87	70.33	79.67	6.73	2.90	9.63
S.Em. ±	0.028	0.624	0.808	0.074	0.058	0.100
C.D. at 5%	0.080	1.751	2.268	0.208	0.162	0.282

Maturity stages (M) × Extraction methods (E)	Fresh shoot weight (mg)	Fresh root weight (mg)	Seedling fresh weight (mg)	Seedling dry weight (mg)	Seedling vigour index I	Seedling vigour index II
$M_1 \times E_1$	129.33	55.33	184.67	10.56	264.50	492.65
$M_1 \times E_2$	276.33	122.00	398.33	14.92	593.90	985.00
$M_1 \times E_3$	352.67	146.00	498.67	17.41	742.07	1229.97
$M_1 \times E_4$	349.67	144.67	494.33	17.32	733.83	1218.13
$M_1 \times E_5$	298.67	125.33	424.00	15.27	644.63	1044.16
$M_1 \times E_6$	261.33	109.33	370.67	12.97	556.00	851.98
$M_1 \times E_7$	227.67	95.67	323.33	11.97	479.47	741.93
$M_1 \times E_8$	156.67	69.33	226.00	11.18	320.83	566.76
$M_1 \times E_9$	169.67	73.00	242.67	11.39	419.30	675.50
$M_1 \times E_{10}$	150.67	67.00	217.67	11.08	302.20	542.92
$M_1 \times E_{11}$	163.00	70.67	233.67	11.27	371.77	615.96
$M_1 \times E_{12}$	232.67	97.33	330.00	12.32	499.87	776.18
$M_1 \times E_{13}$	145.33	63.67	209.00	10.89	296.90	529.86
$M_1 \times E_{14}$	197.67	84.33	282.00	11.69	456.10	701.54
$M_1 \times E_{15}$	238.67	100.67	339.33	12.32	516.10	788.10
$M_1 \times E_{16}$	143.67	61.33	205.00	10.75	281.60	515.79
$M_2 \times E_1$	140.67	59.00	199.67	10.99	517.50	699.57
$M_2 \times E_2$	299.00	132.67	431.67	16.47	871.33	1327.77
$M_2 \times E_3$	426.00	178.67	604.67	17.78	1082.00	1594.48
$M_2 \times E_4$	423.33	177.33	600.67	17.73	1065.17	1578.33
$M_2 \times E_5$	307.33	129.67	437.00	17.30	913.80	1441.30
$M_2 \times E_6$	285.67	121.67	407.33	14.17	859.63	1137.71
$M_2 \times E_7$	255.33	106.67	362.00	12.16	768.13	904.03
$M_2 \times E_8$	166.00	74.67	240.67	11.40	598.83	744.71
$M_2 \times E_9$	192.33	80.67	273.00	11.53	695.73	818.85
$M_2 \times E_{10}$	159.33	68.00	227.33	11.30	578.60	734.23
$M_2 \times E_{11}$	172.67	74.67	247.33	11.48	607.70	761.25
$M_2 \times E_{12}$	265.33	111.67	377.00	13.02	782.57	976.46
$M_2 \times E_{13}$	152.33	70.67	223.00	11.17	545.53	722.47
$M_2 \times E_{14}$	232.67	98.67	331.33	11.75	723.37	850.14
$M_2 \times E_{15}$	274.33	120.67	395.00	13.57	837.37	1085.37
$M_2 \times E_{16}$	147.67	69.67	217.33	11.15	537.60	713.60
$M_3 \times E_1$	142.67	60.67	203.33	11.12	741.40	871.73
$M_3 \times E_2$	319.67	135.67	455.33	17.51	1115.23	1604.45
$M_3 \times E_3$	436.00	183.67	619.67	17.82	1267.47	1746.17
$M_3 \times E_4$	432.33	181.67	614.00	17.75	1242.50	1727.70
$M_3 \times E_5$	325.33	146.00	471.33	17.54	1137.83	1630.91
$M_3 \times E_6$	297.33	122.67	420.00	17.16	1091.10	1555.72
$M_3 \times E_7$	264.67	110.67	375.33	14.19	997.60	1235.08
$M_3 \times E_8$	209.67	88.67	298.33	12.12	830.97	993.99
$M_3 \times E_9$	228.67	96.67	325.33	12.72	946.30	1081.31
$M_3 \times E_{10}$	186.67	79.67	266.33	11.61	810.63	944.51
$M_3 \times E_{11}$	211.67	90.67	302.33	12.19	902.00	1012.23
$M_3 \times E_{12}$	273.67	117.67	391.33	14.88	1037.13	1334.06
$M_3 \times E_{13}$	175.67	74.67	250.33	11.42	781.37	913.38
$M_3 \times E_{14}$	241.67	101.67	343.33	12.97	979.47	1110.43
$M_3 \times E_{15}$	289.67	123.33	413.00	14.99	1058.90	1349.12
$M_3 \times E_{16}$	167.67	72.67	240.33	11.27	767.50	897.49
S.Em. ±	3.696	1.089	4.024	0.219	11.026	18.375
C.D. at 5%	10.376	3.056	11.297	0.616	30.952	51.582

Discussion

Effect of maturity stages

The results show that fruit maturity stage has a strong effect on tomato seed quality and storage life. Seeds from fully ripe fruits (M_3) performed best for seed recovery, 1000 seed weight, germination, seedling growth and vigour both at extraction and during storage. This is because seeds in M_3 are fully developed with complete maturity and nutrient reserves.

Red maturity stage (M_2) also gave good results but was slightly lower than M_3 while turning stage (M_1) had the lowest quality due to immature seeds. Over 3 to 6 months, seed quality decreased in all stages but M_3 maintained higher germination and vigour followed by M_2.

Overall, if harvesting tomato fruits at the dark red stage isn't possible due to rain, pests or other problems fruits at the red stage can be used instead. By choosing the right treatment with proper chemical concentration and soaking time, good seed quality can still be maintained. This ensures healthy germination, strong seedlings and good storage life even without the ideal harvest stage.

Effect of seed extraction methods

This study clearly shows that the way tomato seeds are extracted has a big effect on their quality and how well they store over time. Among all the methods E_3 (10 ml 2% HCl for 60 min) and E_4 (10 ml 2% HCl for 90 min) gave the best results for seed recovery, 1000 seed weight, germination, seedling growth and vigour. Their success is mainly because the acid treatment removes pulp and mucilage well keeps seeds clean and reduces fungus or bacteria problems.

Over 3 to 6 months of storage seed quality slowly went down which is natural as seeds age. But the decline was much smaller in E_3 and E_4 compared to other methods. Manual extraction (E_1) and less effective methods like E_{16} had poor results because the seeds were not cleaned properly and were more likely to spoil.

The heavier seed weight and higher vigour in E_3 and E_4 show that these seeds stayed healthy and strong. These results match earlier research that found acid extraction improves seed cleanliness, germination and storage life.

Overall, E_3 and E_4 can be recommended for producing high-quality tomato seeds that stay good for at least 6 months in storage

Interaction effect of maturity stages and seed extraction methods

Since the results for M_3E_3 (fruit harvested at dark red color and seed extracted by treatment of 10ml 2% HCl/kg slurry for 60 min.), M_2E_3 (fruit harvested at red color and seed extracted by treatment of 10ml 2% HCl/kg slurry for 60 min.) and M_2E_4 (fruit harvested at red color and seed extracted by treatment of 10ml 2% HCl/kg slurry for 90 min.) were almost the same in terms of seed quality and seedling growth and the small differences were not important M_2E_3 and M_2E_4 can be considered the best options. These two treatments performed well consistently. Using M_2E_3 or M_2E_4 in future seed extraction will give good quality seeds. They will help maintain high germination, strong seedlings and good storage life. Choosing either of them is a practical and reliable option for farmers and seed processors.

Conclusion

If harvesting tomato fruits at the dark red stage is not possible due to environmental problems like heavy rainfall, pest attacks or other issues such as market pressure, then fruits at the red maturity stage can be used as an alternative. However, just using red stage fruits is not enough it is very important to use the correct seed extraction method along with it. This includes selecting the right chemical treatment, its concentration and the proper soaking time to remove the gel around the seeds effectively without damaging them.

Using the right combination helps in keeping the seed quality high, even if the fruits are not fully ripe. It ensures that the seeds still show good germination, strong seedling growth and longer storage life. So, even when the ideal dark red stage can't be followed, applying a suitable treatment like 10 ml of 2% HCl for 60 or 90 minutes (as tested in M_2E_3 or M_2E_4) can help maintain seed performance. This makes it easier for farmers and seed producers to manage practical field conditions without compromising on seed quality.

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References

1. Anonymous. International Rules for Seed Testing. 2007. Available from: https://www.fao.org
2. Botey HM, Ochuodho JO, Ngode L, Dwamena H. Fruit maturity and after-ripening improve seed physical and physiological quality of *Solanum aethiopicum* L. Ghana Journal of Science. 2022 Dec 10;63(2):1-1.
3. Demir I, Samit Y. Seed quality in relation to fruit maturation and seed dry weight during development in tomato. Seed Science and Technology. 2001 Oct 3;29(2):453-62.
4. França LV, Croda MD, Nascimento WM, Freitas RA. Physiological quality of eggplant seeds with different extraction and drying methods. Journal of Seed Science. 2013 June;35:51-5.
5. Jones DF. Natural cross-pollination in the tomato. Science. 1916 Apr 7;43(1110):509-10.
6. Kumar A. Effect of Stage of Fruit Maturilty at Harvest and Extraction Methods on Quality and Storage Life of Tomato Seed (Doctoral dissertation). Chaudhary Charan Singh Haryana Agricultural University; 2000.
7. Muniyappa V, Vishwanath K. Influence of Seed Extraction Methods on Seed Quality in Lear Curl Resistant Tomato (*Lycopersicon esculentum* L.) Varieties. Journal of Asian Horticulture. 2006 Aug;412-3.
8. Nakrani AG. Effect of fruit maturity stages and seed extraction methods on seed quality in tomato (*Solanum lycopersicum* L.) 3380 (Doctoral dissertation). JAU Junagadh; 2021.
9. Pozhilarasi SR, Ranjith S, Samuel R, Gracy P. Effects of Different Seed Extraction Methods on Seed Quality Parameters in Tomato var pkm.1. Int.J.Curr.Microbiol.App.Sci. 2022 Nov 1;11(01):199-204.
10. Raval AN, Sasidharan N, Rao KA. Effect of seed extraction procedures on seed quality parameters in tomato. Advances in Life Sciences. 2016;5(20):9020-4.
11. Ravat US. Effect of fruit maturity stages and seed extraction methods on seed quality of brinjal (*Solanum melongena* L.) (Doctoral dissertation). JAU, Junagadh; 2018.

12. Sachan CP, Verma RK, Srivastava AK, Singh SK. Effect of seed extraction methods on its recovery and quality of brinjal. Annals of Horticulture. 2009;2(2):217-8.
13. Singh K. Effect of different methods of seed extraction, packing material and ambient storage condition on vigour of Tomato (*Lycopersicon esculentum* Mill.) Seeds (Doctoral dissertation). Chaudhary Charan Singh Haryana Agricultural University; 2002.
14. Takač A, Popović V, Glogovac S, Dokić V, Kovač D. Effects of fruit maturity stages and seed extraction time on the seed quality of eggplant (*Solanum melongena* L.). Ratarstvo i povrtarstvo/Field and Vegetable Crops Research. 2015;52(1):7-13.