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Pre-harvest FYM-based organic modules and storage conditions influence physical storability of tomato

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Abstract

This study evaluated the combined influence of FYM-based organic modules and three storage conditions on fruit weight, physiological loss in weight (PLW) and shelf life in factorial completely randomized design comprising fruits obtained from 12 pre-harvest treatment combinations from FYM equivalent to 100, 75 or 50% recommended dose of nitrogen (L1, L2 and L3) integrated with four organic modules (M1-M4) were stored open at room temperature (S1), in perforated polybags at room temperature (S2) and in perforated polybags under refrigeration (S3) were replicated thrice during 2020-21 and 2021-22 at the Regional Agricultural Research Station, Warangal, Telangana, India. Postharvest observations were recorded at 0, 4, 8 and, where fruits remained suitable, 12 days after storage (DAS). The pooled data revealed that, L1M1 recorded fruit weights of 275.90, 268.60 and 248.70 g at 0, 4 and 8 DAS. At 8 DAS, S3 (fruits packed in perforated polybags and stored in refrigerator at 7°C) retained the greatest mean fruit weight (216.51 g) and recorded the lowest physiological loss in weight (9.21%), whereas S2 (fruits packed in perforated polybags and stored in room temperature) recorded 199.23 g fruit weight and 16.38% PLW. Among the packing and storage conditions S3 (fruits packed in perforated polybags and stored in refrigerator at 7°C) produced the longest pooled storage-condition mean shelf life (9.86 days), while the interaction treatment L1M1S3 recorded the maximum pooled shelf life (13.33 days).

Conclusion: Refrigerated storage in perforated polybags (S3), particularly for fruits produced under L1M1, provided the best physical weight retention and shelf life within the evaluated treatments.

Keywords: Fruit weight, physiological loss in weight, perforated polybag, refrigerated storage, shelf life, tomato

1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated vegetable crops, valued for its nutritional quality, consumer preference and economic importance. However, being a climacteric and highly perishable fruit, tomato undergoes rapid physiological and biochemical changes after harvest. Continued respiration and moisture loss gradually reduce fruit weight, freshness and marketability, ultimately limiting its shelf life. The postharvest behaviour of tomato is influenced not only by storage conditions but also by genetic, environmental and crop-management factors operating before harvest (Arah *et al.*, 2015; Bertin and Génard, 2018) [4, 5]. Therefore, maintaining fruit quality after harvest requires attention to both pre-harvest production practices and postharvest management.

Organic production has gained increasing importance in tomato cultivation as an approach that makes greater use of farm-derived nutrient sources, beneficial microorganisms and botanical inputs. Farmyard manure (FYM) provides organic matter as well as plant nutrients, while microbial and organic formulations such as *Trichoderma*, *Pseudomonas*, VAM, Panchagavya, Jeevamruth and vermiwash are commonly used as components of organic crop-management systems. Apart from their role during crop growth, pre-harvest nutrient-management practices can influence the characteristics of fruits at harvest and, consequently, their behaviour during subsequent storage.

Differences in the postharvest performance of tomatoes grown under different nutrient-management systems have also been reported. Laxmi *et al.* (2015) [10] observed variations in fruit

quality and shelf life when tomato was supplied with different combinations of organic manures and fertilizers. Pradhan and Srijaya (2022) ^[16] further reported better storability of organically grown tomatoes under refrigerated conditions, with lower physiological loss in weight, reduced respiration and lower loss of firmness. These findings suggest that the conditions under which fruits are produced may have an important bearing on how well they retain their quality after harvest.

Postharvest storage conditions are equally important in determining the marketable life of tomato. Perforated polymeric packaging can reduce excessive moisture loss while allowing adequate ventilation around the fruits. Poudel *et al.* (2022) ^[15] and Haile (2018) ^[8] reported that packaging material considerably influenced weight loss and marketability of stored tomatoes. Refrigeration further helps in slowing physiological deterioration during storage, although individual quality attributes may respond differently to reduced temperature (Toor and Savage, 2006; Pék *et al.*, 2010) ^[20, 14]. Pre-harvest nutrition also influences fruit size, biochemical composition and tissue integrity and can consequently affect postharvest behaviour.

The study evaluated whether 12 FYM-based pre-harvest treatment combinations (A) differed in their physical storability under open room storage (S1), perforated-polybag room storage (S2) and perforated-polybag refrigerated storage (S3). The objective was to quantify preharvest organic treatments and storage effects on fruit weight, PLW and shelf life.

2. Materials and Methods

2.1 Experimental material and pre-harvest treatments

Tomato fruits were obtained during 2020-21 and 2021-22 from the field experiment conducted at the Regional Agricultural Research Station, Warangal, Telangana, India. The pre-harvest factor comprised 12 combinations of three FYM levels and four organic modules. The FYM levels were L1, FYM equivalent to 100% recommended dose of nitrogen (RDN); L2, FYM equivalent to 75% RDN; and L3, FYM equivalent to 50% RDN integrated with four organic modules, namely M1: (Soil application of *Trichoderma viride* @ 2kg/ton of FYM+250 kg/ha neem cake+ Spraying *Trichoderma viride* 5g/litre + 3% Panchagavya + 5% neem oil + Bt @1g/litre at 10 days interval), M2: (Soil application of *Pseudomonas fluorescens* @ 2.0 kg enriched in 1 ton + 250 kg/ha neem cake+ Spraying *Pseudomonas fluorescens* 5g/litre + 10% Vermiwash + @ 500 ml GCG extract per 10litres of water + NPV @ 250 LE/ha at 10 days interval), M3: (Soil Application of VAM @ 10 Kg/ton of FYM + 250 kg/ha neem cake + Spraying 10% Jeevamruth + 5% NSKE + 5g/litre *Metarhizium anisopliae*+ *Trichoderma* + *Pseudomonas spp.* @ 5g/litre at 10 days interval) and M4: (Application of Waste decomposer @ 40l/ton of FYM +Spraying 10% Amruthpani + 5% Neemastra + 5g/litre *Beauveria bassiana* + Spraying mass multiplied waste decomposer culture is diluted @ 1:3 ratio with water at 10 days interval).

2.2 Storage treatments and experimental design

Five fruits from each pre-harvest treatment were used for evaluating the physical storability parameters in a factorial completely randomized design with three replications. Storage treatments comprised S1 (open storage at room temperature), S2 (storage in perforated polyethylene bags under room temperature) and S3 (storage in perforated polyethylene bags under refrigerated conditions at 7 °C). Thus, 12 pre-harvest combinations × 3 storage conditions produced 36 treatment combinations in each season.

2.3 Observations and statistical analysis

2.3.1 Average fruit weight (g): It was recorded using an analytical balance at 0, 4 and 8 days after storage (DAS) and at

12 DAS, where fruits remained suitable.

2.3.2 Physiological loss in weight (PLW) %: It was calculated as the percentage weight loss of the initial weight. The initial weight of each sample per replication was taken before packing. The weight of the sample was taken on four-day intervals after setting up the experiment. The formula used for the calculation was:

$$PLW\% = (\text{Initial weight} - \text{Final weight} / \text{Initial Weight}) * 100$$

PLW was recorded at 4, 8 and 12 DAS and expressed as percentage loss relative to initial fruit weight. Shelf life was recorded in days. Data were analyzed for pre-harvest treatment (A), storage (S) and A × S interaction using the reported SE(m)± and CD at 5%.

2.3.3 Shelf life (days): The storage shelf life of the tomato fruits was calculated by counting the number of days required for them to attain the last stage of ripening, but up to the stage when they remained still acceptable for marketing in all the treatment combinations.

At 12 DAS, observations were confined to L1M1S3 and L1M3S3 because fruits in the remaining treatment-storage combinations had reached the rejection endpoint. Asterisks denote spoiled/unavailable fruit; these entries were not assigned zero, estimated, imputed or extrapolated. The data was analysed using OP stat software.

2.3.4 Correlation: Pearson's correlation analysis was performed using R statistical software to determine the relationships among fruit weight, physiological loss in weight (PLW) and shelf life. The correlations were calculated across the 12 pooled pre-harvest treatment means. Fruit weight and PLW recorded at 8 DAS and pooled treatment means for shelf life were used for the correlation analysis. Twelve-DAS observations were excluded.

The Pearson coefficient is:

$$r = \frac{\sum (xi - \bar{x}) \sum (yi - \bar{y})}{\sqrt{\sum (xi - \bar{x})^2 \sum (yi - \bar{y})^2}}$$

Correlations were interpreted as associations rather than causation.

3. Results and Discussion

3.1 Average fruit weight (g)

Average fruit weight declined with storage duration. L1M1 recorded the maximum treatment means at 0, 4 and 8 DAS in 2020-21 (276.36, 269.95 and 248.99 g) and 2021-22 (275.44, 267.26 and 248.40 g). The corresponding pooled values were 275.90, 268.60 and 248.70 g. At 8 DAS, pooled storage means were 206.66 g under S1, 199.23 g under S2 and 216.51 g under S3; treatment, storage and interaction effects were significant.

At 12 DAS, L1M1S3 retained 247.85 and 247.75 g in the two seasons and 247.80 g in pooled data. L1M3S3 recorded 234.47, 233.44 and 233.96 g, respectively. All other observations were unavailable. Refrigeration combined with perforated packaging reduces transpiration and respiratory depletion, explaining better mass retention. Similar reductions in weight loss with polyethylene packaging were reported by Haile (2018) ^[8] and Poudel *et al.* (2022) ^[15]. The significant organic module treatments and storage interaction at 8 DAS in both years and in the pooled analysis shows that the effect of storage condition depended on the pre-harvest treatment imposed. The combination L1M1S3 consistently retained the highest fruit weight, followed by L1M3S3, indicating that fruits produced under superior organic nutrition responded better to refrigerated storage. This suggests a

complementary effect between pre-harvest organic nutrient management and post-harvest low-temperature packaging.

The higher fruit weight retained by L1M1 and L1M3 throughout storage may be attributed to better pre-harvest nutritional status of fruits produced under FYM equivalent to 100% RDN in combination with effective organic modules. FYM improves soil physical condition, microbial activity, nutrient release and moisture retention, which favour better root growth, nutrient uptake and assimilate translocation towards developing fruits. Hence, fruits from L1M1 and L1M3 might have possessed better initial size, firmness, cellular integrity and moisture-holding capacity than those from reduced FYM levels. Similar improvements in tomato fruit quality and shelf life due to organic manures and biofertilizers were reported by Laxmi *et al.* (2015)^[10], who observed that organic manures and nutrient integration improved fruit yield, quality, and shelf life in tomato. Manickam *et al.* (2022)^[11] also reported that judicious use of organic manures enhanced tomato fruit quality by maintaining soil fertility and improving nutrient availability.

The gradual decline in fruit weight from 0 to 8 DAS in all treatments was mainly due to physiological loss in weight caused by transpiration, respiration and utilization of stored substrates. Tomato being a climacteric and highly perishable fruit continues to respire after harvest; therefore, loss of water and respiratory depletion of reserves progressively reduce fresh weight. The superiority of S3, i.e., storage in perforated polybags under refrigerated condition, at 4 and 8 DAS clearly indicates the beneficial role of low temperature combined with packaging in maintaining fruit weight. Refrigeration slows down respiration, ethylene activity, ripening and enzymatic softening, while perforated polybags reduce moisture loss by maintaining relatively higher humidity around the fruit surface. Haile (2018)^[8] reported that polyethylene packaging reduced physiological weight loss and decay in tomato, and perforated polyethylene bags maintained better marketability at later stages of storage. Similar trends were noticed by Pradhan and Srijaya (2022)^[16] when tomatoes grown with indigenous liquid organic manures and stored in refrigerated conditions showed lesser PLW, loss of firmness and respiration rate, and lower microbial load compared to conventional counterparts.

3.2 Physiological loss in weight (%)

The lower physiological loss in weight (PLW) recorded in L1M1, L1M2 and L1M3, particularly under 100% FYM equivalent to RDN, indicates that balanced organic nutrition improved fruit tissue integrity and moisture retention during storage. Organic

manures enhance soil microbial activity, nutrient availability and calcium uptake, which contribute to stronger cell walls and membranes, thereby reducing transpiration losses after harvest. The substantially higher PLW observed under L3M4 suggests that inadequate nutrient supply (50% FYM equivalent to RDN) adversely affected fruit structural stability, making the fruits more susceptible to water loss and senescence. PLW increased from 4 to 8 DAS. At 4 DAS, pooled storage means were 3.39, 3.50 and 1.48% under S1, S2 and S3; at 8 DAS, they were 13.27, 16.38 and 9.21%, respectively. The storage effect was significant at both dates. L1M1 recorded pooled PLW of 2.64% at 4 DAS and the lowest treatment mean at 8 DAS (9.86%). At 12 DAS, the only recorded pooled observations were 10.17% for L1M1S3 and 10.69% for L1M3S3.

The superiority of S3 (perforated polybags under refrigerated conditions at 7 °C) across both years and pooled analysis demonstrates the beneficial effect of low temperature combined with appropriate packaging. Refrigerated storage suppresses respiration, ethylene evolution and transpiration, while perforated polybags maintain high relative humidity and reduce vapour pressure deficit around the fruits, thereby minimizing moisture loss. In the present study, S3 consistently recorded the lowest PLW (1.15 and 9.25% during 2020–21; 1.80 and 9.16% during 2021–22; and 1.48 and 9.21% in pooled data at 4 and 8 DAS, respectively), clearly indicating its effectiveness in preserving fruit freshness.

The interaction effects further strengthen this conclusion. The combination L1M1S3 exhibited the minimum PLW throughout storage (1.05% and 5.15% during 2020–21; 1.70% and 5.05% during 2021–22; and 1.37% and 5.10% in pooled analysis), whereas L3M4S2 consistently recorded the highest PLW. These findings indicate that fruits produced under optimum organic nutrition responded more favourably to refrigerated storage than fruits grown under lower nutrient levels. The present findings corroborate those of Moneruzzaman *et al.* (2009)^[13], who evaluated different storage systems in tomato and reported that refrigerated conditions markedly reduced physiological loss in weight and prolonged marketable shelf life by slowing respiration, moisture loss, delayed ripening and reduced fruit weight.

The lower PLW under S3 reflects reduced vapour-pressure-driven water loss and slower respiration at low temperature. Packaging maintains higher humidity around the fruit surface, while perforations allow ventilation. These responses agree with reports that packaging and refrigeration reduce postharvest weight loss in tomato (Haile, 2018; Poudel *et al.*, 2022)^[8, 15].

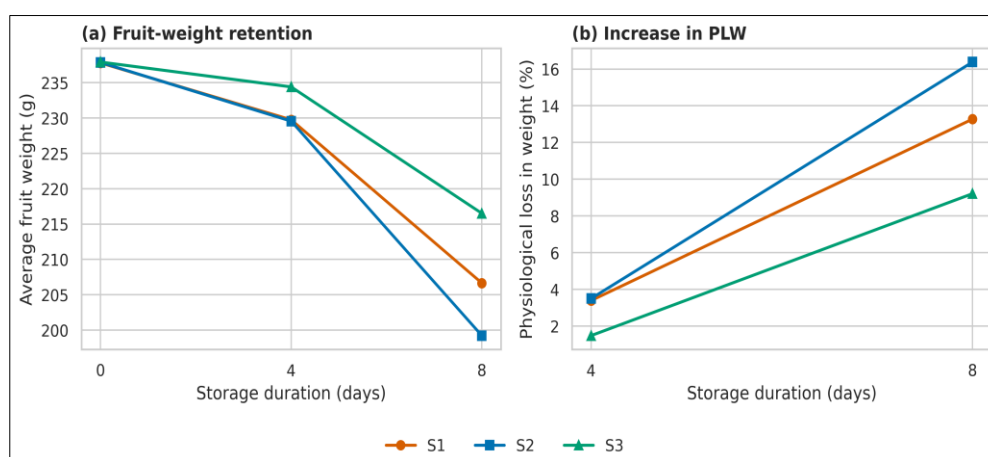


Fig 1: Changes in pooled storage-condition means for (a) average fruit weight and (b) physiological loss in weight (PLW). S1 = open storage at room temperature; S2 = perforated polybags at room temperature; S3 = perforated polybags under refrigeration. Only common observation dates are plotted

3.3 Shelf life (days)

Shelf life was significantly affected by treatment, storage and their interaction in both years and pooled analysis. L1M1 recorded the highest treatment means of 10.44 days in 2020-21, 10.78 days in 2021-22 and 10.33 days in pooled data; L1M3 followed with 10.11, 10.33 and 10.00 days. The pooled S3 mean (9.86 days) exceeded S1 and S2 (8.44 days each). L1M1S3 recorded the maximum pooled shelf life (13.33 days), followed by L1M3S3 (13.00 days). While, the lowest shelf life (pooled) was observed in L3M4 (50% FYM equivalent to RDN + Organic Module-4) with 8.22 days, followed by L3M2 and L3M3 (8.33 days each) indicating rapid deterioration under open room-temperature storage combined with lower FYM levels.

Storage under S3 (perforated polybags under refrigerated conditions) significantly prolonged shelf life (9.86 days) compared with S1 (8.44 days) and S2 (8.44 days).

Shelf life represents the cumulative outcome of several physiological, biochemical and microbiological processes occurring after harvest. The enhanced shelf life observed in fruits obtained from L1M1 (FYM equivalent to 100 per cent RDN + Organic Module-I) and L1M3 (FYM equivalent to 100 per cent RDN + Organic Module-III) may be attributed to improved nutritional status of the crop, which contributed to stronger cell wall architecture, greater dry matter accumulation and better membrane stability. The favourable response exhibited by Organic Module-I could be linked to the combined influence of *Trichoderma viride*, Panchagavya, neem oil and *Bacillus thuringiensis*. Panchagavya contains growth-promoting substances and beneficial microorganisms that improve physiological efficiency and metabolite accumulation associated with fruit quality. Likewise, Organic Module-III comprising VAM, Jeevamruth, NSKE and *Metarhizium anisopliae* enhances nutrient mobilization and microbial activity, ultimately contributing to delayed senescence. Balanced nutrition derived from FYM and biologically active organic inputs promotes better cell wall development, membrane stability and antioxidant activity, thereby reducing metabolic deterioration during storage. Similar observations were reported by Pradhan and Srijaya (2022)^[16], who reported superior postharvest storability of organically grown tomatoes, particularly under refrigerated storage, as evidenced by lower physiological loss in weight, reduced respiration rate and lower loss of firmness. The authors associated these responses with greater longevity and delayed senescence of organically produced fruits.

Storage-induced changes were strongly governed by temperature and packaging. Fruits maintained under S3 (perforated polyethylene bags under refrigerated storage) consistently outperformed those stored under S1 (open storage at room temperature) and S2 (storage in perforated polyethylene bags under

room temperature). The beneficial effect of refrigeration may be attributed to suppression of respiration rate, delayed ethylene biosynthesis and reduced activity of enzymes involved in tissue softening.

Tomato being a climacteric fruit undergoes a sharp increase in respiration and ethylene production during ripening. Lowering storage temperature slows the climacteric rise, delays colour development and prolongs marketability (Kader, 2002). Refrigerated storage also restricts the activity of polygalacturonase, pectin methyl esterase and cellulase, thereby slowing degradation of pectic substances and maintaining firmness. The perforated polyethylene bags used under S3 created a favourable microenvironment around the fruits by maintaining higher relative humidity while permitting adequate gaseous exchange. This reduced transpiration losses without causing anaerobic conditions. Comparable observations were reported by Akand *et al.* (2015)^[2] and Abrar *et al.* (2016)^[1].

Although packaging under room temperature conditions reduced direct moisture loss, fruits stored under S2 continued to respire actively due to prevailing ambient temperatures. Consequently, rapid ripening and senescence curtailed the storage period. Open storage, on the other hand, accelerated moisture loss owing to greater vapour pressure deficit between fruit tissues and the surrounding atmosphere.

The significant extension of shelf life under S3 (storage in perforated polybags under refrigerated conditions) emphasizes the importance of temperature management in preserving tomato fruits. Refrigerated storage slows respiration, suppresses ethylene production and delays enzymatic softening, while perforated packaging maintains a favourable humidity regime that minimizes moisture loss. Rai *et al.* (2021)^[17] reported that refrigerated packaging significantly prolonged tomato shelf life and maintained post-harvest quality by reducing respiratory metabolism and water loss.

The superiority of the interaction combinations L1M1S3 and L1M3S3 indicates that fruits produced under optimum FYM nutrition responded more efficiently to refrigerated storage than fruits grown under lower nutrient regimes. This complementary effect of pre-harvest nutrient management and post-harvest storage has also been highlighted by Mditshwa *et al.* (2022)^[12], who observed that improved nutritional status enhanced fruit resistance to physiological breakdown and contributed to extended storage longevity. The longer shelf life under refrigeration is attributable to suppression of respiration, ethylene-mediated ripening and enzymatic softening. The results are consistent with reports of extended tomato shelf life under suitable packaging and lower-temperature storage (Tigist *et al.*, 2013; Poudel *et al.*, 2022)^[19, 15].

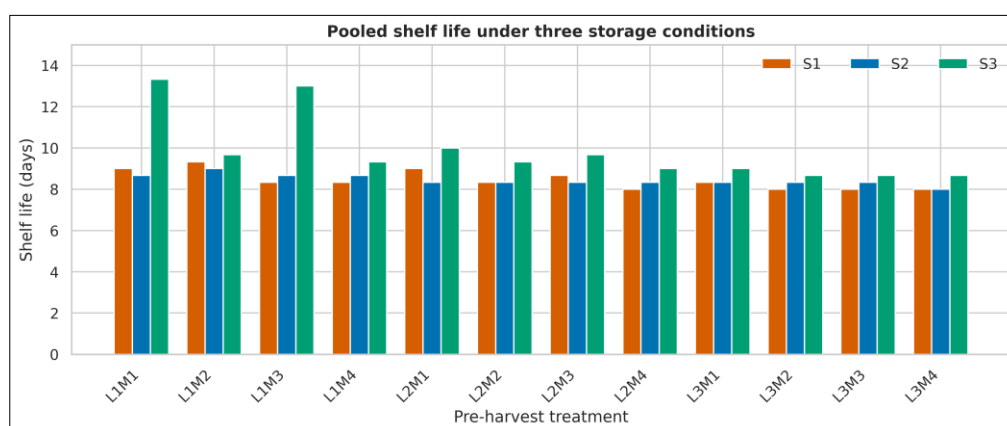


Fig 2: Pooled shelf life of the 12 pre-harvest treatment combinations under S1, S2 and S3. Refrigerated perforated-polybag storage (S3) markedly extended shelf life in L1M1 and L1M3

3.4 Interrelationships among physical storability attributes

The physical attributes displayed a coherent treatment response. All three relationships are statistically significant at $p < 0.01$. Fruit weight was strongly and positively correlated with shelf life ($r = 0.92$, $p < 0.001$) and strongly and negatively correlated with PLW

($r = -0.91$, $p < 0.001$). PLW was negatively correlated with shelf life ($r = -0.80$, $P = 0.0018$). Thus, treatments retaining greater fruit mass generally showed lower proportional weight loss and longer marketable life. These are associations across 12 pooled treatment means and do not establish causation.

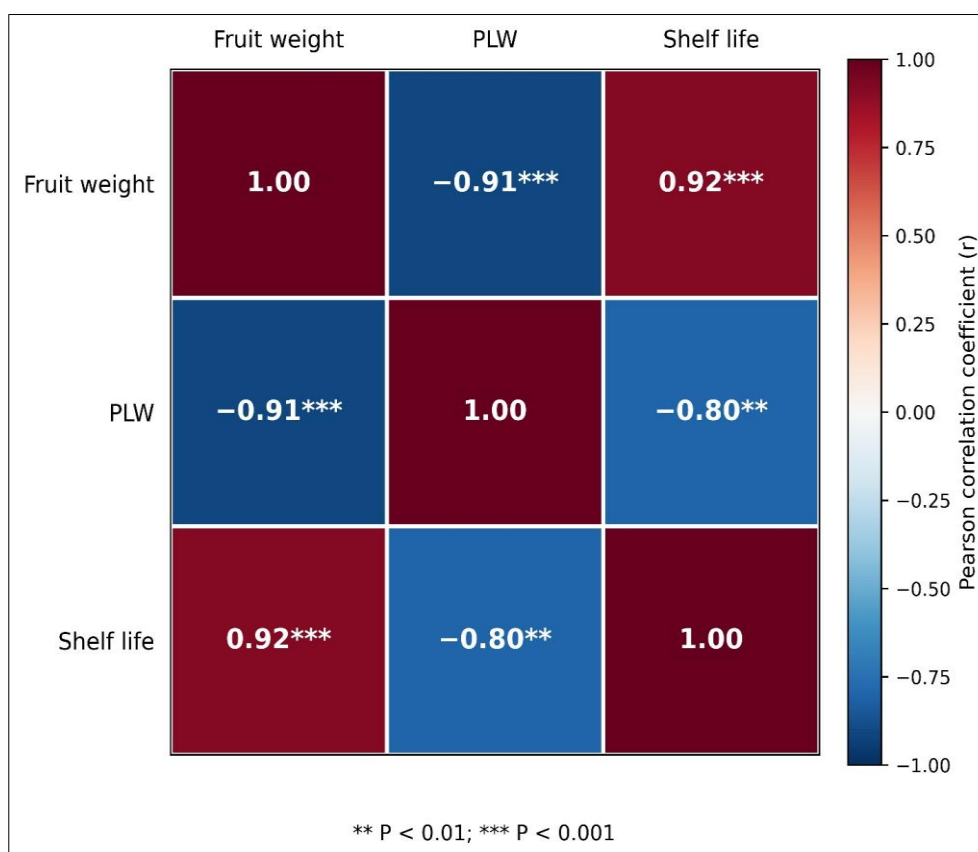


Fig 3: Pearson correlation heatmap among fruit weight, physiological loss in weight (PLW) and shelf life of tomato ($n = 12$). ** $p < 0.01$; *** $p < 0.001$. Fruit weight and PLW were evaluated at 8 DAS, while shelf life represents the pooled treatment mean.

The strong relationships observed among fruit weight, PLW and shelf life are physiologically consistent with earlier postharvest studies in tomato. The strong negative association between fruit weight and PLW ($r = -0.91$) indicates that treatments exhibiting greater physiological weight loss retained less fruit mass during storage. Weight loss in tomato is largely associated with continued transpiration and respiration, and its progression becomes greater as storage duration increases. Kabir *et al.* (2020) [9] similarly documented progressive weight loss in tomato during storage and demonstrated the importance of prompt cooling for maintaining postharvest physicochemical quality.

The positive relationship between fruit weight and shelf life ($r = 0.92$), together with the negative relationship between PLW and shelf life ($r = -0.80$), further suggests that better moisture and mass retention was associated with prolonged storability. Dladla *et al.* (2023) [6] reported that packaging and storage conditions significantly influenced physiological weight loss in tomato and that packaged fruits subjected to cold storage maintained quality more effectively than unpackaged fruits. Similarly, Shehata *et al.* (2021) [18] demonstrated that postharvest treatments that restricted

weight loss also extended tomato shelf life and maintained fruit quality. These findings support the present correlation pattern, in which reduced PLW was associated with greater fruit-weight retention and longer shelf life. However, the correlations observed in the present study represent associations across pooled treatment means and should not be interpreted as evidence of a direct causal relationship.

3.8 Scope and limitations

The study provides two-season evidence from a factorial combination of pre-harvest organic management and postharvest storage. Nevertheless, interpretation is limited by the absence of recorded firmness, colour, respiration, ethylene and microbial measurements in the present dataset. Further, most treatment-storage combinations became unavailable before 12 DAS, preventing a complete factorial comparison at the final observation. The 12-DAS results therefore document survival and retained quality only for L1M1S3 and L1M3S3 and do not establish a statistical ranking against spoiled treatments.

Table 1a: Effect of different levels of FYM integrated with organic modules and different storage, packing conditions on fruit weight (g) at 0,4,8,12 days of storage in tomato for the year 2020-21

Treatment	Fruit weight at 0 days				Fruit weight at 4 days				Fruit weight at 8 days				Fruit weight at 12 days		
	S1	S2	S3	Mean	S1	S2	S3	Mean	S1	S2	S3	Mean	S1	S2	S3
L1M1	276.18	276.59	276.31	276.36	268.23	268.21	273.42	269.95	246.81	238.08	262.08	248.99	*	*	247.85
L1M2	258.37	258.07	258.11	258.19	251.04	250.57	255.24	252.28	228.33	217.51	237.19	227.68	*	*	*
L1M3	261.65	262.03	262.40	262.03	253.99	254.26	259.40	255.88	233.84	223.56	247.84	235.08	*	*	234.47
L1M4	253.52	253.15	252.77	253.15	245.95	244.92	249.91	246.93	222.19	211.94	230.01	221.38	*	*	*
L2M1	244.95	245.29	245.71	245.32	237.65	237.84	242.95	239.48	214.44	208.29	228.82	217.18	*	*	*
L2M2	237.43	237.04	236.68	237.05	230.38	230.19	233.90	231.49	207.13	200.50	213.79	207.14	*	*	*
L2M3	240.81	241.18	241.56	241.18	233.66	233.49	238.81	235.32	212.65	205.28	223.10	213.68	*	*	*
L2M4	229.11	228.74	228.35	228.73	221.43	221.07	225.60	222.70	195.77	188.08	200.97	194.94	*	*	*
L3M1	220.72	221.09	221.49	221.10	213.48	214.17	219.03	215.56	191.23	186.27	200.86	192.79	*	*	*
L3M2	210.56	210.95	211.32	210.94	203.95	203.61	208.67	205.41	178.23	174.51	187.52	180.09	*	*	*
L3M3	219.31	218.94	218.55	218.93	212.36	211.52	216.23	213.37	187.03	178.14	195.61	186.93	*	*	*
L3M4	205.56	205.95	206.31	205.94	198.62	198.60	203.66	200.29	165.26	161.48	173.42	166.72	*	*	*
Mean	238.18	238.25	238.30		230.90	230.70	235.57		206.91	199.47	216.77				
	A	S	AXS		A	S	AXS		A	S	AXS				
SE(m)±	0.15	0.08	0.26		0.183	0.09	0.32		0.93	0.47	1.61				
C.D. @5%	0.43	N/A	0.74		0.52	0.26	N/A		2.63	1.32	4.56				

* Tomato fruits were unavailable for observation because all fruits had spoiled.

Table 1b: Effect of different levels of FYM integrated with organic modules and different storage, packing conditions on fruit weight (g) at 0,4,8,12 days of storage in tomato for the year 2021-22

Treatment	Fruit weight at 0 days				Fruit weight at 4 days				Fruit weight at 8 days				Fruit weight at 12 days		
	S1	S2	S3	Mean	S1	S2	S3	Mean	S1	S2	S3	Mean	S1	S2	S3
L1M1	275.27	275.66	275.39	275.44	265.55	265.52	270.69	267.26	246.22	237.51	261.46	248.40	*	*	247.75
L1M2	257.51	257.21	257.25	257.33	248.53	248.07	252.68	249.76	227.78	216.99	236.63	227.13	*	*	*
L1M3	260.78	261.15	261.52	261.15	251.45	251.72	256.81	253.33	233.28	223.02	247.25	234.51	*	*	233.44
L1M4	252.67	252.31	251.93	252.30	243.49	242.48	247.41	244.46	221.65	211.43	229.46	220.85	*	*	*
L2M1	244.14	244.48	244.89	244.50	235.28	235.46	240.52	237.09	213.92	207.80	228.27	216.66	*	*	*
L2M2	236.64	236.25	235.89	236.26	228.08	227.89	231.56	229.17	206.64	200.02	213.28	206.65	*	*	*
L2M3	240.01	240.38	240.76	240.38	231.32	231.15	236.42	232.97	212.14	204.79	222.57	213.17	*	*	*
L2M4	228.34	227.98	227.59	227.97	219.21	218.86	223.34	220.47	195.30	187.63	200.49	194.47	*	*	*
L3M1	219.98	220.35	220.75	220.36	211.34	212.03	216.84	213.40	190.78	185.83	200.38	192.33	*	*	*
L3M2	209.86	210.25	210.61	210.24	201.91	201.57	206.59	203.36	177.81	174.09	187.07	179.66	*	*	*
L3M3	218.58	218.21	217.83	218.20	210.24	209.40	214.06	211.23	186.58	177.71	195.14	186.48	*	*	*
L3M4	204.87	205.26	205.63	205.25	196.64	196.61	201.62	198.29	164.87	161.09	173.00	166.32	*	*	*
Mean	237.39	237.46	237.50		228.59	228.40	233.21		206.42	198.99	216.25				
	A	S	AXS		A	S	AXS		A	S	AXS				
SE(m)±	0.94	0.47	1.64		0.18	0.09	0.31		0.52	0.26	0.90				
C.D. @5%	2.67	N/A	N/A		0.51	0.26	N/A		1.47	0.74	2.55				

* Tomato fruits were unavailable for observation because all fruits had spoiled

Table 1c: Effect of different levels of FYM integrated with organic modules and different storage, packing conditions on fruit weight (g) at 0,4,8,12 days of storage in tomato (pooled)

Treatment	Fruit weight at 0 days				Fruit weight at 4 days				Fruit weight at 8 days				Fruit weight at 12 days		
	S1	S2	S3	Mean	S1	S2	S3	Mean	S1	S2	S3	Mean	S1	S2	S3
L1M1	275.73	276.12	275.85	275.90	266.89	266.86	272.06	268.60	246.52	237.80	261.77	248.70	*	*	247.80
L1M2	257.94	257.64	257.68	257.75	249.78	249.32	253.96	251.02	228.05	217.25	236.91	227.40	*	*	*
L1M3	261.21	261.59	261.96	261.59	252.72	252.99	258.11	254.61	233.56	223.29	247.54	234.80	*	*	233.96
L1M4	253.09	252.73	252.35	252.72	244.72	243.70	248.66	245.69	221.92	211.68	229.73	221.11	*	*	*
L2M1	244.55	244.88	245.30	244.91	236.46	236.65	241.73	238.28	214.18	208.05	228.54	216.92	*	*	*
L2M2	237.04	236.64	236.28	236.65	229.23	229.04	232.73	230.33	206.89	200.26	213.54	206.90	*	*	*
L2M3	240.41	240.78	241.16	240.78	232.49	232.32	237.62	234.14	212.39	205.04	222.84	213.42	*	*	*
L2M4	228.72	228.36	227.97	228.35	220.32	219.96	224.47	221.58	195.54	187.85	200.73	194.71	*	*	*
L3M1	220.35	220.72	221.12	220.73	212.41	213.10	217.93	214.48	191.00	186.05	200.62	192.56	*	*	*
L3M2	210.21	210.60	210.96	210.59	202.93	202.59	207.63	204.38	178.02	174.30	187.30	179.87	*	*	*
L3M3	218.94	218.57	218.19	218.57	211.30	210.46	215.14	212.30	186.81	177.92	195.37	186.70	*	*	*
L3M4	205.21	205.60	205.97	205.59	197.63	197.61	202.64	199.29	165.06	161.28	173.21	166.52	*	*	*
Mean	237.78	237.85	237.90		229.74	229.55	234.39		206.66	199.23	216.51				
	A	S	AXS		A	S	AXS		A	S	AXS				
SE(m)±	1.15	0.58	3.98		1.10	0.55	3.79		2.03	1.02	7.04				
C.D. @5%	2.27	1.13	7.85		2.16	1.08	7.48		4.01	2.00	13.87				

* Tomato fruits were unavailable for observation because all fruits had spoiled.

Table 2a: Effect of different levels of FYM integrated with organic modules and different storage, packing conditions on physiological loss in weight (%) at 0,4,8,12 days of storage in tomato for the year 2020-21

Treatment	PLW (%) at 4 days				PLW (%) at 8 days				PLW (%) at 12 days		
	S1	S2	S3	Mean	S1	S2	S3	Mean	S1	S2	S3
L1M1	2.88	3.03	1.05	2.32	10.64	13.92	5.15	9.90	*	*	10.36
L1M2	2.84	2.90	1.12	2.29	11.63	15.72	8.11	11.82	*	*	*
L1M3	2.93	2.96	1.14	2.34	10.63	14.68	5.55	10.29	*	*	10.46
L1M4	2.98	3.25	1.13	2.46	12.36	16.28	9.01	12.55	*	*	*
L2M1	2.98	3.04	1.12	2.38	12.46	15.08	6.88	11.47	*	*	*
L2M2	2.97	2.89	1.17	2.34	12.76	15.41	9.67	12.62	*	*	*
L2M3	2.97	3.19	1.14	2.43	11.70	14.88	7.64	11.41	*	*	*
L2M4	3.36	3.36	1.21	2.64	14.55	17.78	11.99	14.77	*	*	*
L3M1	3.28	3.13	1.11	2.51	13.36	15.75	9.31	12.81	*	*	*
L3M2	3.14	3.48	1.25	2.62	15.35	17.28	11.26	14.63	*	*	*
L3M3	3.17	3.39	1.07	2.54	14.72	18.64	10.50	14.62	*	*	*
L3M4	3.37	3.57	1.29	2.74	19.61	21.59	15.94	19.05	*	*	*
Mean	3.07	3.18	1.15		13.31	16.42	9.25				
	A	S	AXS		A	S	AXS		A	S	AXS
SE(m)±	0.05	0.02	0.08		0.38	0.19	0.67				
C.D. @5%	0.14	0.07	0.24		1.09	0.54	N/A				

* Tomato fruits were unavailable for observation because all fruits had spoiled.

Table 2b: Effect of different levels of FYM integrated with organic modules and different storage, packing conditions on physiological loss in weight (%) at 0,4,8,12 days of storage in tomato for the year 2021-22

Treatment	PLW (%) at 4 days				PLW (%) at 8 days				PLW (%) at 12 days		
	S1	S2	S3	Mean	S1	S2	S3	Mean	S1	S2	S3
L1M1	3.52	3.67	1.70	2.96	10.54	13.83	5.05	9.81	*	*	10.04
L1M2	3.48	3.54	1.77	2.93	11.54	15.63	8.02	11.73	*	*	*
L1M3	3.57	3.60	1.79	2.99	10.54	14.60	5.46	10.20	*	*	10.73
L1M4	3.62	3.89	1.79	3.10	12.27	16.20	8.91	12.46	*	*	*
L2M1	3.62	3.68	1.78	3.03	12.37	15.00	6.78	11.38	*	*	*
L2M2	3.61	3.53	1.83	2.99	12.67	15.33	9.58	12.53	*	*	*
L2M3	3.61	3.83	1.79	3.08	11.61	14.80	7.55	11.32	*	*	*
L2M4	3.99	3.99	1.86	3.28	14.47	17.69	11.91	14.69	*	*	*
L3M1	3.92	3.77	1.77	3.15	13.27	15.67	9.23	12.72	*	*	*
L3M2	3.78	4.12	1.90	3.27	15.26	17.19	11.18	14.54	*	*	*
L3M3	3.81	4.03	1.72	3.19	14.63	18.56	10.41	14.53	*	*	*
L3M4	4.01	4.21	1.94	3.39	19.52	21.52	15.87	18.97	*	*	*
Mean	3.71	3.82	1.80		13.23	16.34	9.16				
	A	S	AXS		A	S	AXS				
SE(m)±	0.40	0.20	0.40		0.22	0.11	0.38				
C.D. @5%	N/A	0.56	N/A		0.62	0.31	1.07				

* Tomato fruits were unavailable for observation because all fruits had spoiled.

Table 2c: Effect of different levels of FYM integrated with organic modules and different storage, packing conditions on physiological loss in weight (%) at 0,4,8,12 days of storage in tomato (Pooled)

Treatment	PLW at 4 days				PLW at 8 days				PLW at 12 days		
	S1	S2	S3	Mean	S1	S2	S3	Mean	S1	S2	S3
L1M1	3.20	3.35	1.37	2.64	10.59	13.88	5.10	9.86	*	*	10.17
L1M2	3.16	3.23	1.44	2.61	11.58	15.67	8.06	11.77	*	*	*
L1M3	3.25	3.28	1.47	2.67	10.59	14.64	5.50	10.24	*	*	10.69
L1M4	3.30	3.57	1.46	2.78	12.31	16.24	8.96	12.50	*	*	*
L2M1	3.30	3.36	1.45	2.70	12.41	15.04	6.83	11.43	*	*	*
L2M2	3.29	3.21	1.50	2.67	12.72	15.37	9.62	12.57	*	*	*
L2M3	3.29	3.51	1.46	2.75	11.65	14.84	7.60	11.36	*	*	*
L2M4	3.67	3.67	1.53	2.96	14.51	17.73	11.95	14.73	*	*	*
L3M1	3.60	3.45	1.44	2.83	13.31	15.71	9.27	12.76	*	*	*
L3M2	3.46	3.80	1.58	2.95	15.31	17.24	11.22	14.59	*	*	*
L3M3	3.49	3.71	1.39	2.86	14.68	18.60	10.45	14.58	*	*	*
L3M4	3.69	3.89	1.61	3.06	19.56	21.56	15.90	19.01	*	*	*
Mean	3.39	3.50	1.48		13.27	16.38	9.21				
	A	S	AXS		A	S	AXS				
SE(m)±	0.21	0.10	0.71		0.70	0.35	2.41				
C.D. @5%	0.41	0.20	1.41		1.37	0.69	4.76				

* Tomato fruits were unavailable for observation because all fruits had spoiled.

Table 3: Effect of different levels of FYM integrated with organic modules and different storage, packing conditions on shelf life (days) of tomato

Treatment	Shelf life (days)											
	2020-21				2021-22				Pooled			
	S1	S2	S3	Mean	S1	S2	S3	Mean	S1	S2	S3	Mean
L1M1	9.33	8.67	13.33	10.44	9.67	9.00	13.67	10.78	9.00	8.67	13.33	10.33
L1M2	9.33	8.67	10.33	9.44	9.67	9.00	10.00	9.56	9.33	9.00	9.67	9.33
L1M3	8.67	8.67	13.00	10.11	8.67	9.00	13.33	10.33	8.33	8.67	13.00	10.00
L1M4	8.33	8.67	9.67	8.89	8.67	9.00	10.00	9.22	8.33	8.67	9.33	8.78
L2M1	8.67	8.33	10.33	9.11	9.00	8.67	10.67	9.44	9.00	8.33	10.00	9.11
L2M2	8.67	8.33	9.33	8.78	9.00	8.67	9.67	9.11	8.33	8.33	9.33	8.67
L2M3	8.67	8.33	9.67	8.89	9.00	8.67	10.00	9.22	8.67	8.33	9.67	8.89
L2M4	8.00	8.33	9.00	8.44	8.33	8.67	9.33	8.78	8.00	8.33	9.00	8.44
L3M1	8.33	8.67	9.00	8.67	8.67	9.00	9.67	9.11	8.33	8.33	9.00	8.56
L3M2	8.00	8.33	8.67	8.33	8.33	8.67	9.00	8.67	8.00	8.33	8.67	8.33
L3M3	8.00	8.33	8.67	8.33	8.33	8.67	9.00	8.67	8.00	8.33	8.67	8.33
L3M4	8.33	8.00	9.00	8.44	8.67	8.33	9.33	8.78	8.00	8.00	8.67	8.22
Mean	8.53	8.44	10.00		8.83	8.78	10.31		8.44	8.44	9.86	
	A	S	AXS		A	S	AXS		A	S	AXS	
SE(m)±	0.19	0.09	0.32		0.16	0.08	0.28		0.17	0.08	0.29	
C.D. @5%	0.53	0.26	0.92		0.46	0.23	0.8		0.47	0.24	0.82	

* Tomato fruits were unavailable for observation because all fruits had spoiled.

Table 4: Pearson correlations among physical storability attributes at 8 DAS (n = 12)

Variable	Fruit weight	PLW	Shelf life
Fruit weight	1.00	-0.91***	0.92***
PLW	-0.91***	1.00	-0.80***
Shelf life	0.92***	-0.80***	1.00

Fruit weight and PLW were measured at 8 DAS; shelf life is the pooled treatment mean. Twelve-DAS data were excluded because only two combinations remained available.

4. Conclusion

Pre-harvest FYM-organic module treatments and storage conditions significantly influenced the physical storability of tomato. S3 retained the greatest fruit weight and lowest PLW at 8 DAS and produced the longest storage-condition mean shelf life. L1M1S3 recorded the maximum pooled shelf life and was one of only two combinations remaining available at 12 DAS. Therefore, L1M1 followed by refrigerated perforated-polybag storage was the best physical storability treatment evaluated.

Disclaimer (Artificial Intelligence)

Grammarly and ChatGPT- AI assistance- were used in language preparation, designing the figures and confirming that the authors verified all scientific content and source data.

Competing Interests

Authors have declared that no competing interests exist.

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