Unraveling rationale behind tomato (Solanum Lycopersicum L.) shelf life: Role of fruit biochemical, morpho- physiological traits in extending shelf life

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Abstract

Prolonging the keeping quality of tomatoes is very essential for reduction of great losses in quality and quantity. Fruit shelf life is ripening-associated complex trait affected by many quantitative fruit quality traits. In this study, 30 tomato germplasm lines were characterized for very important less pursued shelf life and its contributing traits. Shelf life ranged from 10.50 to 34.43 days. Slower dehydration rate noticed in tender fruit tissues in turning stage. Slow pace in rate of change in physiological losses in fruit weight led to high shelf life. Fruit firmness ranged from 2.49 to 5.76 kg/cm^2 and pericarp thickness from 1.33 to 6.70 mm. High shelf life germplasm lines contained 6.98–19.29 mg/100g and 8.64–13.38 mg/100g of fruit calcium and magnesium content respectively. The fruit epicuticular wax content varied from 34.64 to 96.77 µg/cm^2. Calcium, magnesium, and epicuticular wax decrease respiration rate, maintain firmness, delay senescence, reduces incidence of physiological disorders and extend fruit storage life. Higher shelf life in germplasm lines P-4, L-00191, L-03686, AR-23, PKM-1, and Bony best are contributed by higher firmness and epicuticular wax content and high shelf life in Red ball is due to higher firmness, pericarp thickness, calcium, magnesium and epicuticular wax content.

1. Introduction

Tomato (*Solanum lycopersicum* L.), is one of the extensively cultivated and consumed vegetable crops in the world. Its production can serve as a source of income for most rural and periurban farmers in the developing countries and it's consumption constitutes very essential part of people's diet (Arah et al. 2015). It is rich in lycopene, β-carotene, ascorbic acid, folic acid, phenolic acids, and flavonoids (Arab and Steck 2000; Khachik et al. 2002) which have anti-aging, blood purifying, anti-cancerous properties and reduces the incidence of many cardiovascular disorders (Freeman and Reimers 2011). It is a perishable fruit crop with a relatively short shelf life after ripening thus experiences remarkable post-harvest losses. Globally post-harvest losses of tomatoes are estimated up to 25–42% (Arah et al. 2015) and up to 50% in developing countries (Delina and Mahendran 2009).

The fruits perishability is cumulative effect of sub-standard post-harvest operations viz., improper storage, inadequate transportation and insufficient processing, preservation facilities. This resulted in fruits chemical and physical changes such as loss of weight, sugar and acid contents, respiration, transpiration, softening of pulp and microbial decay which greatly contributes to high post-harvest losses (Garcia et al. 2019). Consequently, large volumes of low quality tomatoes sold at throw-away prices and interns the farmers, processors and traders fail to get expected return for their produce (Sinha 2019).

The post-harvest shelf life is one of the most important traits for commercially grown tomatoes. Prolonging the keeping quality of tomatoes is very essential for both successful marketing and reduction of huge losses in quality and quantity (Salliba et al. 2001). This will help farmers more time to market their produce before fruit quality is degraded (Osei et al. 2020). Minimizing these losses can increase their supply without bringing additional land under cultivation. Therefore, the need for reduction of post-harvest losses is paramount important.

The pre-harvest treatments of fruits with vinegar, salicylic acid (Chavan and Sakhale 2020), origanum oil, calcium chloride, and anti-sense RNA technology are efficient methods in extending the shelf life of tomatoes but these technologies are laborious, unfeasible in farmer's field and need social acceptance. Therefore, Identification of tomato germplasm lines with high shelf life and other associated fruit quality traits is the best option and safest way (Yogendra and Gowda 2013).

Many earlier studies reported that the fruit shelf life is a ripening-associated complex trait affected by several low inherited quantitative fruit biochemical, morpho-physiological and yield traits. Assessing the genetic variability in germplasm lines for the selection of desirable parents is a key issue for planning a sound plant breeding program. The high shelf life of germplasm lines is very essential as these lines can be used in hybridization as shelf life donor parent with high yielding recepient parent for development of high yielding coupled with appreciable shelf life hybrid and/or variety (Pavan et al. 2018). There is a popular saying that "A ton of fruits and vegetables saved is equivalent to two tons produced". Keeping all the above considerations, we have attempted to estimate the genetic variability among the tomato germplasm lines for shelf life and its contributing traits, identified the germplasm lines with good shelf life, and unraveled the reasons for the longer shelf life of germplasm lines.

2. Material And Methods

2.1 Experimental site : The present investigation was carried out by conducting the field and lab experiments during the 2016 summer and rainy seasons at the Department of Genetics and Plant Breeding, University of Agricultural and Horticultural Sciences, Navule, Shivamogga, (13.9739 ^{0}N, 75.5791 ^{0}E), Karnataka, India.

2.2 Experimental materials: The experimental material consists of 30 diverse tomato germplasm lines collected from the Kitturu Rani Chennamma College of Horticulture, Arabhavi, Karnataka, India. For comparative analysis of tomato germplasm lines, 'Arka Vikas', a prominent high yielding tomato variety released from ICAR-Indian Institute of Horticultural Research, Bengaluru, Karnataka, India is used as check variety.

2.3 Evaluation of experimental materials: The 30 tomato germplasm lines and standard check were planted in the field during the 2016 summer and rainy seasons in two separate contiguous blocks in Randomized Complete Block Design with two replications. The standard crop production and protection practices were followed to raise healthy plants and were evaluated for fruit quality traits.

2.4 Data collection: Data were recorded on fruits of five randomly selected plants avoiding border plants in each germplasm line (Table I, Pavan and Gangaprasad 2022). The germplasm lines were evaluated for 22 traits such as 5 fruit biochemical traits viz., TSS, pH, lycopene, ascorbic acid, titratable acidity, 12 morpho-physiological traits viz., calcium, magnesium, epicuticular wax content, physiological loss in weight, fruit length, diameter, pericarp thickness, fruit weight, firmness, pulp content, locule number, shelf life and 5 yield attributing traits plant height, number of branches, number of clusters, number of fruit/cluster, yield/plant.

2.5 Statistical analysis: Initially, the mean for each trait from five fruits in each plant was estimated then the mean of five plants of each germplasm line from each replication was estimated. Finally mean of both the replications was computed as the trait mean. The collected mean data of fruit quality traits from each replication was analyzed for descriptive statistics viz., mean, absolute range (highest-lowest), standardized range [(highest-lowest)/mean] and Analysis of Variance (ANOVA) (Panse and Sukhatme 1964), Phenotypic co-efficient of variation (PCV), Genotypic co-efficient of variation (GCV) (Burton and Devane 1953), Broad sense heritability (Hanson et al. 1956), Genetic Advance as per cent of Mean (GAM) (Johnson et al. 1955) using 'WINDOSTAT' statistical package.

Table I: The procedure of recording data on tomato fruit quality traits

Fruit biochemical traits		
Sl. No.	**Traits**	**Procedure of measurement**
1	Total Soluble Salts (TSS) (%)	Mean Brix value measured using Erma hand refractometer in the fresh tomato juice
2	pH	Recorded using a Siemens pH meter
3	Lycopene (mg/100g)	Analysed by Lichtenthaler spectrophotometric method, 1987
4	Ascorbic acid (mg/100g)	Determined by 2,6-Dichlorophenol indophenol (DCPIP) method, AOAC, 2006
5	Titratable acidity (%)	Determined by AOAC titration method, 2000
Fruit morpho-physiological traits		
Sl. No.	**Traits**	**Procedure of measurement**
6	Calcium (mg/100g)	The fruit samples collected at the red ripe stage were processed in the laboratory, dried, and powdered. 1gm of powdered fruit samples was pre-digested with HNO_3 for 12 hours then treated with di-acid (HNO_3: $HClO_4$ in 10:4 ratio) mixture and digested on sand bath till a snow-white residue obtained. Then it cooled and the volume was made up to 100ml using 6 N HCl. The samples were analyzed for their calcium and magnesium composition using an Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) system.
7	Magnesium (mg/100g)	
8	Physiological loss in weight (PLW %)	It is measured as fruits harvested at breaker stage weighed initially and decline in weight recorded at turning stage [3rd days after harvest (DAH)], pink stage (8th DAH) and red stage (12th DAH). The mean physiological loss in weight of fruits was computed by the difference between the initial weight and the weight on the day of sampling and expressed in percentage.
9	Fruit epicuticular wax (μg/cm^2)	Fruit epicuticular wax content was estimated according to Ebercon et al. (1977)
10	Fruit length (cm)	Measured from stem end to blossom end using digital vernier caliper after cutting the fruit vertically
11	Fruit diameter (cm)	Mean equatorial diameter of fruit measured at the maximum perimeter using digital vernier caliper
12	Fruit weight (g)	Average weight in grams of whole fruits harvested
13	Fruit firmness (kg/cm^2)	The mean pressure required for puncturing red ripe fruits near to stem and blossom ends using fruit penetrometer
14	Pericarp thickness (mm)	An average thickness of the pericarp measured using digital vernier calliper in the transversely cut fruits
15	Pulp content (%)	Percent ratio of weight of pulp after removing fruit juice and seeds to the fruit weight
16	Locule number (Nos.)	Counted after cutting of fruit transversely from the middle portion
17	Shelf life (Days)	Average number of days taken by the fruits harvested at breaker stage to show first visible shrinkage on the fruit surface when fruit kept on the shelf
Fruit yield traits		
Sl. No.	**Traits**	**Procedure of measurement**
18	Plant height (cm)	Measured from base of the plant to the tip of the plant at the time of physiological maturity
19	Number of branches (Nos.)	Total number of branches per plant were counted

Fruit biochemical traits		
20	Number of clusters (Nos.)	Total number of fruits cluster on each plant were counted
21	Number of fruit/cluster (Nos.)	Total number of fruits per cluster on each plant were counted
22	Yield/plant (g)	Fresh weight of fruits per plant recorded at various pickings

3. Results

3.1 Variability for fruit quality and yield traits

The significant differences were recorded for TSS, pH, lycopene, ascorbic acid, titratable acidity, fruit length, diameter, pericarp thickness, fruit weight, firmness, pulp content, locule number, shelf life, plant height, number of branches, number of clusters, number of fruit/cluster and yield/plant which indicated the prevalence of abundant variability among the germplasm lines (Table II). These results were further reflected by broader absolute range for the all the characters (Pavan et al. 2018). The standardised range varied from 0.46 (pH) to 3.76 (yield/plant). The higher standardized range followed by higher estimates PCV recorded for yield/plant, fruit weight, pericarp thickness, titratable acidity, locule number and TSS (Table III).

The PCV ranged between 11.34% (pH) to 82.29% (Fruit weight) and GCV ranged between 10.68% (pH) to 81.33% (Fruit weight). Higher PCV and GCV with close correspondence between them observed for TSS, ascorbic acid, titratable acidity, fruit length, fruit weight, pericarp thickness, locule number, plant height, number of branches, number of clusters and yield/plant. The Broad-sense heritability ranged from 51.80% (Fruit firmness) to 99.50% (Yield/plant) and genetic advance as per cent of mean ranged between 20.71% (pH) to 165.58% (Fruit weight). The high broad sense heritability coupled with high GAM recorded for TSS, pH, lycopene, ascorbic acid, titratable acidity, fruit length, diameter, weight, pericarp thickness, pulp content, locule number, shelf life, plant height, number of branches, number of clusters, number of fruits/cluster and yield/plant.

3.2 Variability for physiological loss in weight and rate of change in physiological loss in weight

3.2.1 Physiological loss in weight (PLW%): The principal cause of fruit softening and shriveling during post-harvest storage of fruits is water loss followed by weight loss and it is expressed as physiological loss in fruit weight. As per maturity indices of tomato classification by United States Department of Agriculture, 'Turning' stage means 10–30% of fruit surface in aggregate shows definite change in color from green to tannish yellow, pink, red, or a combination thereof. 'Pink' stage means 30–60% of fruit surface in aggregate shows pink or red and 'Red' stage means > 90% of fruit surface in aggregate is red.

The physiological loss in fruit weight on turning stage (3rd DAH), pink stage (8th DAH), and red stage (12th DAH) was estimated. As evident from the mean, there is an increase in the physiological loss in fruit weight as the number of days after fruit harvest increases which indicates a linear association between physiological loss in fruit weight and number of days after fruit harvest (Figure I).

Table II: Analysis of variance for fruit biochemical, morpho-physiological and yield traits in tomato germplasm lines

Source of variation	Degrees of freedom	Mean sum of squares								
		TSS	pH	Lycopene	Ascorbic acid	Titratable acidity	Fruit length	Fruit diameter	Fruit weight	Fruit firmness
Replication	01	0.23	0.24	0.29	0595.45	0.12	172.08	272.19	0212.77	0.67
Genotypes	29	4.93**	0.76**	0.92**	2031.26**	0.79**	259.79**	353.59**	1043.97**	1.59**
Error	29	0.02	0.02	0.05	0081.25	0.02	005.57	017.48	0006.17	0.30
Source of variation	Degrees of freedom	Mean sum of squares								
		Pericarp thickness	Pulp content	Locule number	Shelf life	Plant height	Number of branches	Number of clusters	Number of fruit/cluster	Yield/plant
Replication	01	0.84	437.07	00.06	149.69	470.45	17.04	02.34	0.20	2097.36
Genotypes	29	8.93**	574.56**	11.36**	151.61**	1242.48**	17.87**	48.96**	2.38**	253251.56**
Error	29	0.05	048.02	00.04	012.05	11.91	00.43	00.13	0.08	0307.20
**Significant at p = 0.01										

Table III: Estimates of parameters specifying variability for fruit quality and yield traits in tomato germplasm lines

Sl. No.	Characters	Absolute range		Standardized range	Mean	Genotypic Variance σ^2_g	Phenotypic variance σ^2_p	PCV (%)	GCV (%)	Broad sense heritability (%)	GAM @ 5% (%)
		Lowest	Highest								
1	TSS (%)	0.53	4.65	1.80	2.29	1.23	1.25	48.78	48.35	98.20	98.73
2	pH	3.41	5.26	0.46	4.02	0.19	0.21	11.34	10.68	88.70	20.71
3	Lycopene (mg/100g)	0.45	3.49	1.25	2.44	0.22	0.26	21.06	19.11	82.30	35.72
4	Ascorbic acid (mg/100g)	10.62	135.38	1.48	82.37	487.50	568.76	28.92	26.77	85.70	51.06
5	Titratable acidity (%)	0.48	2.45	1.89	1.04	0.19	0.22	44.98	42.00	87.20	80.81
6	Fruit length (cm)	10.79	44.84	1.20	28.73	63.55	69.13	29.33	28.12	91.90	55.54
7	Fruit diameter (cm)	17.55	51.64	1.08	31.71	84.03	101.51	32.01	29.13	82.80	54.59
8	Fruit weight (g)	2.95	56.74	2.58	20.81	259.45	265.63	82.29	81.33	97.70	165.58
9	Fruit firmness (kg/cm^2)	1.50	7.49	1.36	4.42	0.32	0.62	27.51	19.81	51.80	29.37
10	Pericarp thickness (mm)	1.33	7.59	2.08	3.01	2.22	2.27	51.20	50.68	98.00	103.35
11	Pulp content (%)	32.51	80.91	0.80	61.03	131.63	179.66	22.15	18.96	73.30	33.44
12	Locule number	2.10	8.18	1.87	3.25	2.83	2.87	51.23	50.91	98.80	104.23
13	Shelf life (Days)	10.50	34.43	1.07	22.36	34.89	46.94	31.27	26.96	74.30	47.88
14	Plant height (cm)	41.53	105.65	0.82	77.84	307.64	319.55	22.73	22.30	96.30	45.47
15	Number of branches	5.10	12.11	0.81	8.68	4.36	4.79	25.31	24.15	91.00	47.47
16	Number of clusters	4.78	20.03	1.43	10.73	12.21	12.34	32.99	32.82	98.90	67.24
17	Number of fruit/cluster	1.93	5.21	1.09	3.00	0.58	0.66	27.62	25.83	87.50	49.77
18	Yield/plant (g)	130.35	1512.75	3.76	408.47	63236.09	63543.29	68.07	67.91	99.50	139.55
PCV	=	Phenotypic co-efficient of variation	GAM	=	Genetic advance as per cent of mean						
GCV	=	Genotypic co-efficient of variation									

The physiological loss in fruit weight on 3rd DAH was least in TLB-133 (0.68%) and highest in L-00398 (29.13%) with mean 5.16%. Similarly physiological loss in fruit weight at 8th DAH and 12th DAH was least and high respectively in Patriot (1.56%), L-00398 (31.42%) with mean 9.10%

and TLB-133 (3.46%), AR-4 with mean 13.32% (Table IV). Mallik et al. (1996) reported that tomato fruit showed the lowest physiological weight loss 7.7–9.7% after 6 days of storage under ambient conditions.

3.2.2 Rate of change in physiological loss in weight: The rate of change in physiological loss in fruit weight at 8th DAH compared to 12th DAH was higher in most of genotypes including check (Table IV). The contrasting results of negative values for rate of change in physiological loss in fruit weight were reported in pod land pink, L-04787, AR-30 and AR-17 for turning to pink stage and in genotypes AR-90, AR-29, TLB-20 for pink to red stage (Figure II).

At 8th DAH, the rate of change in physiological loss in fruit weight was ranged from 0.66% (Patriot) to 4.66% (AR-23) and at 12th DAH, it was varied from 0.58% (TLB-133) to 5.78% (AR-23). The physiological losses in fruit weight at 3rd, 8th ,12th DAH and rate of change in

Table IV: Variability for physiological loss in weight, rate of change in physiological loss in weight and shelf life in tomato germplasm lines

Sl. No.	Germplasm lines	Physiological loss in weight (PLW) (%)			Rate of change in PLW		Shelf life (Days)
		Turning stage (PLW3)	Pink stage (PLW8)	Red stage (PLW12)	PLW8 - PLW3	PLW12 - PLW8	
1	Black prince	2.12	6.34	8.37	4.22	2.03	19.65
2	AR-8	0.91	2.89	11.89	1.98	9.00	15.75
3	Pod land pink	6.59	4.11	4.86	-2.48	0.75	10.75
4	AR-56	2.26	6.14	7.34	3.88	1.20	18.85
5	AR-28	2.48	7.87	12.61	5.39	4.74	21.43
6	P2L-0091	1.64	4.71	6.39	3.07	1.68	22.25
7	L-04780	1.33	24.31	25.19	22.98	0.88	24.00
8	AR-34	6.32	7.33	10.18	1.01	2.85	10.50
9	Patriot	0.90	1.56	3.85	0.66	2.29	28.53
10	TLB-133	0.68	2.87	3.46	2.19	0.59	30.78
11	PKM-1	3.10	21.28	30.97	18.18	9.69	27.68
12	L-00398	29.13	31.42	32.57	2.29	1.15	26.50
13	AR-47	10.35	14.81	32.81	4.46	18.00	23.50
14	AR-4	2.02	19.62	38.22	17.60	18.60	20.15
15	AR-90	15.99	20.90	16.65	4.91	-4.25	12.50
16	L-04787	12.53	3.72	4.71	-8.81	0.99	24.93
17	Bony best	1.27	3.73	5.72	2.46	1.99	25.13
18	AR-19	1.59	4.56	6.70	2.97	2.14	21.50
19	AR-30	8.50	6.29	8.30	-2.21	2.01	14.98
20	AR-5	1.25	3.79	28.65	2.54	24.86	18.48
21	AR-7	2.98	7.86	12.08	4.88	4.22	24.83
22	AR-29	2.63	6.75	6.68	4.12	-0.07	14.50
23	AR-17	6.32	5.20	10.65	-1.12	5.45	24.63
24	TLB-20	2.21	6.12	4.34	3.91	-1.78	16.25
25	L-03686	19.83	22.23	27.56	2.40	5.33	28.88
26	P-4	1.83	4.71	6.65	2.88	1.94	30.78
27	TLB-130	0.95	3.13	4.32	2.18	1.19	23.13
28	AR-23	3.43	8.09	13.87	4.66	5.78	27.75
29	L-00191	1.58	5.06	6.77	3.48	1.71	30.10
30	Red ball	2.21	5.66	7.14	3.45	1.48	34.43
Lowest		0.68	1.56	3.46	-8.81	-4.25	10.50
Highest		29.13	31.42	38.22	22.98	24.86	34.43
Mean		5.16	9.10	13.32	3.94	4.21	22.36
*Negative values indicate slower rate of dehydration							

physiological loss in weight at 8th and 12th DAH were significantly lower in all genotypes except for L-03686 and L-00398.

3.3 Variability of high shelf life tomato germplasm lines for shelf life contributing traits

Among thirty tomato germplasm lines, ten high shelf life tomato germplasm lines with > 25 days of shelf life were selected and compared with high yielding standard check variety Arka Vikas for fruit firmness, pericarp thickness, calcium, magnesium, epicuticular wax content and yield/plant (Table V).

The shelf life ranged from 10.50days (AR-34) to 34.43days (Red ball) with mean of 22.36days (Yogendra and Gowda 2013; Pavan et al. 2018) (Figure III). High shelf life genotypes recorded significantly higher fruit firmness compared to check. The fruit firmness was ranged from 2.49kg/cm^2 (L-00398) to 5.76kg/cm^2 (AR-23) with mean 4.05kg/cm^2. The pericarp thickness varied from 1.33mm (L-03686) to 6.70mm (Red ball) with mean 3.09mm. The Red ball recorded significantly higher pericarp thickness compared to check. Hedau et al. (2008) reported that pericarp thickness varied from 1.41 to 4.87mm.

The calcium and magnesium are the major constituent of cell wall and play an essential function in the integrity and stability of the cell membrane. Fruit calcium in high shelf life tomato germplasm lines ranged from 6.98mg/100g (Patriot) to 19.29mg/100g (Red ball) with mean 9.84 mg/100g and magnesium ranged from 8.64 mg/100g (TLB-133) to 13.38 mg/100g (Red ball) with mean 12.02mg/100g. The fruit epicuticular wax in high shelf life tomato germplasm lines ranged from 34.64µg/cm^2 (L-00398) to 96.77µg/cm^2 (Red ball) with mean 55.13µg/cm^2.

3.4 Comparison of high shelf life tomato germplasm lines with check variety for shelf life attributing traits

A comparative analysis of high shelf life tomato germplasm lines with check variety Arka Vikas was performed for shelf life attributing and yield traits (Figure IV). All high shelf life tomato germplasm lines had significantly higher fruit firmness and epicuticular wax content (except TLB-133, Patriot, and L-00398) compared to check variety. Red ball recorded considerably fruit firmness (3.75kg/cm^2), pericarp thickness (6.70mm), calcium (19.30mg/100g), magnesium (13.38mg/100g) and epicuticular wax content (96.77µg/cm^2).

Table V: Comparison of high shelf life tomato germplasm lines with check variety for shelf life attributing traits

Sl. No.	Germplasm lines	Shelf life (Days)	Fruit firmness (kg/cm^2)	Pericarp thickness (mm)	Calcium (mg/100g)	Magnesium (mg/100g)	Fruit epicuticular wax (µg/cm^2)	Yield/ plant (g)
1	Red ball	34.43*	3.75*	6.70*	19.30*	13.38	96.77*	539.98
2	P-4	30.78*	5.12*	3.28	7.61	11.74	43.29*	239.05
3	TLB-133	30.78*	4.08*	3.26	8.47	8.64	34.80	339.90
4	L-00191	30.10*	3.75*	2.04	9.13	12.13	62.21*	359.45
5	L-03686	28.88*	5.19*	1.33	7.03	12.78	55.11*	218.75
6	Patriot	28.53*	3.41*	2.45	6.98	13.21	35.97	338.73
7	AR-23	27.75*	5.76*	2.26	10.88	10.59	96.05*	302.58
8	PKM-1	27.68*	3.79*	2.64	7.28	13.28	38.08*	243.40
9	L-00398	26.50*	2.49*	3.21	8.11	12.24	34.64	320.80
10	Bonybest	25.13*	3.11*	3.69	13.59*	12.25	54.36*	575.38
Arka Vikas (check)		17.10	1.68	4.24	11.15	14.43	20.67	1155.50
Mean		29.06	4.05	3.09	9.84	12.02	55.13	387.80
S.Em. ±		0.83	0.32	0.46	1.24	0.46	7.53	38.20
C.D. 5%		1.87	0.73	1.04	0.55	1.04	17.02	86.41
*Significant at p = 0.05								

4. Discussion

The higher standardized range followed by higher estimates PCV suggested the possibility of exploiting variability for fruit quality and yield traits. The germplasm lines which recorded extremities values for a specific character can be used as contrasting parents in hybridisation programme to study the inheritance and gene action governing the respective character (Dar and Sharma 2011; Joseph et al. 2014; Meena et al. 2015; Rakesh et al. 2018).

Higher PCV and GCV with close correspondence between them indicated that environmental had meagre influence and hence selection can be made based on their phenotypic performance. The high broad sense heritability coupled with high GAM indicated the role of additive gene effects for TSS, pH, lycopene, ascorbic acid, titratable acidity, fruit length, diameter, weight, pericarp thickness, pulp content, locule number, shelf life, plant height, number of branches, number of clusters, number of fruits/cluster and yield/plant. Hence selection would be rewarding for improvement of such traits. Moderate broad sense heritability and high GAM recorded for fruit firmness indicated good response to selection and in turn better chances of improving trait (Vinod et al. 2012; Narolia et al. 2012; Meena and Bahadur 2014; Ravindra et al. 2015; Rakesh et al. 2018).

The prevalence of wide variation for physiological loss in fruit weight is directly correlated with respiration rate of fruits which intern depends on keeping quality of fruits. The tomato fruit experiences physiological loss in fruit weight during breaker to turning followed by pink and red stages. It is an important physical quality parameter determining wholesomeness and shelf life of fruits. Most fruits contain 80–85% water by weight and major portion of it is lost by transpiration followed by evaporation (Wilkinson 1965). Therefore, there is need to maintain adequate water to prolong shelf life of fruits even when they lose some amount of water during storage.

When fruit is harvest at breakers stage, the respiration rate of fruit slowly goes on increasing i.e. climacteric rise with number of days elapsed from harvesting. The ethylene is rapidly produced in fruit at breaker stage, drives series of reactions that together define fruit ripening process (Moneruzzaman et al. 2008).

The higher rate of change in physiological loss in fruit weight signified the higher dehydration rate that happened in tender tissue of turning stage tomatoes (Moneruzzaman et al. 2008). The negative values for rate of change in physiological loss in fruit weight for turning to pink stage and pink to red stage indicated the slower rate of dehydration. The high shelf life tomato germplasm lines had slow respiration rate which resulted in slow rate of water loss as well as weight loss. The slow physiological losses in fruit weight and slow pace in rate of change in physiological loss in weight may contribute to higher shelf life in tomato germplasm lines.

The longer shelf life germplasm lines had slower phase of biochemical reactions. There is natural tendency for perishable fruits and vegetables to degrade to simpler inorganic compounds such as Co_2, H_2O, and NH_3 through spontaneous biochemical reaction which leads to loss of free energy and reduction in shelf life and other (Moneruzzaman et al. 2008). Cultivation of these varieties can be transported to long-distance markets and farmers can get good price for their produce during price crash periods in local markets (Moneruzzaman et al. 2008; Dar and Sharma 2011).

The fruit firmness is one of the critical components of internal fruit quality and it is the final index on which the consumer's perception and decision to purchase a given batch of tomatoes depends. With advancement in fruit ripening, changes in fruit texture, structure, and composition of their cell walls by breakdown of insoluble protopectin into soluble pectin takes place leads to softening of fruits which considerably influences post-harvest performance, i.e. transportation, shelf life, and pathogen resistance. Pericarp thickness assumes prime importance among parameters which condition fruit firmness. Thick pericarp fruits would stand long-distance transport and keep well for longer days (Chakraborty et al. 2007).

The calcium and magnesium interact with pectic acid in the cell wall to form calcium and magnesium pectate, thereby having a direct influence on fruit firmness (Marschner 1995; Jones 1999). It has beneficial effects on marketing and storage of fruits through inhibition of abnormal senescence and reduction of respiration rate, ethylene synthesis, protein breakdown, weight loss, and reduces incidence of physiological disorders during storage (Parker and Maalekuu 2013; Abrol et al. 2017). The fruit containing low calcium and magnesium are sensitive to physiological and pathological disorders, consequently have short shelf life.

Fruit epicuticular waxes are complex mixtures of very long-chain lipid compounds and main components of the cuticle deposited on outer surface of fruits (Lara 2019). They retards rate of moisture loss, maintain turgidity, plumpness and extend shelf life (Wills and Golding 2016). Waxing influences respiration rate by decreasing oxygen and increasing carbon dioxide content in the internal atmosphere of the fruit (Parker and Maalekuu 2013). Under this restricted air exchange condition, benefits of modified atmosphere may be achieved. Kumar et al. (2018) reported that in tomato mutants, ripening inhibitor and non-ripening had significant increase in C18 cutin monomers which had increase in waxes characterized by reduced water loss rate during post-harvest.

The higher shelf life in P-4, L-00191, L-03686, AR-23, PKM-1 and Bony best contributed by higher fruit firmness and epicuticular wax content. Similarly, higher fruit firmness is responsible for high shelf life in TLB-133, Patriot, and L-00398. High shelf life in Red ball might be due to higher fruit firmness, pericarp thickness, calcium, magnesium and epicuticular wax content.

5. Conclusions

The fruit shelf life is affected by physiological loss in weight, rate of change in physiological loss in fruit weight, fruit firmness, pericarp thickness, calcium, magnesium and epicuticular wax content. The slow physiological loss in fruit weight contribute to higher shelf life in tomato germplasm lines. Red ball, P-4, TLB-133, and L-00191 were identified as high shelf life germplasm lines. Breeder can use these lines as high shelf life parents in hybridization with high yielding lines for development of high yielding-high shelf life hybrids and/or varieties. Farmers can cultivate high shelf life tomato varieties which can be transported to long-distance markets before fruit quality degraded and can get better price for their produce during price crash periods in local markets. Consumer can store high shelf life tomato for long time in normal room condition without refrigeration. This would reduce huge losses in terms of quality and quantity of tomato.

Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Pavan, Gangaprasad. The first draft of the manuscript was written by Pavan and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

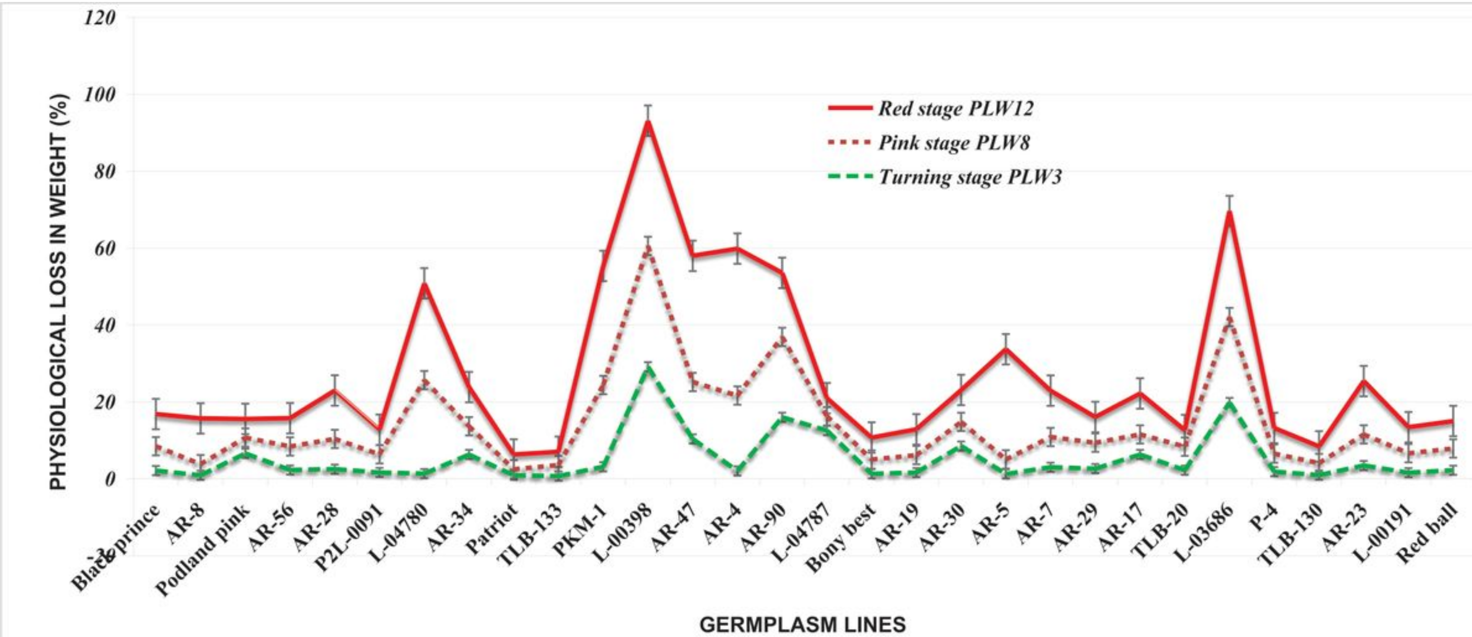

Figure 1

Association of physiological loss in fruit weight v/s number of days after fruit harvest

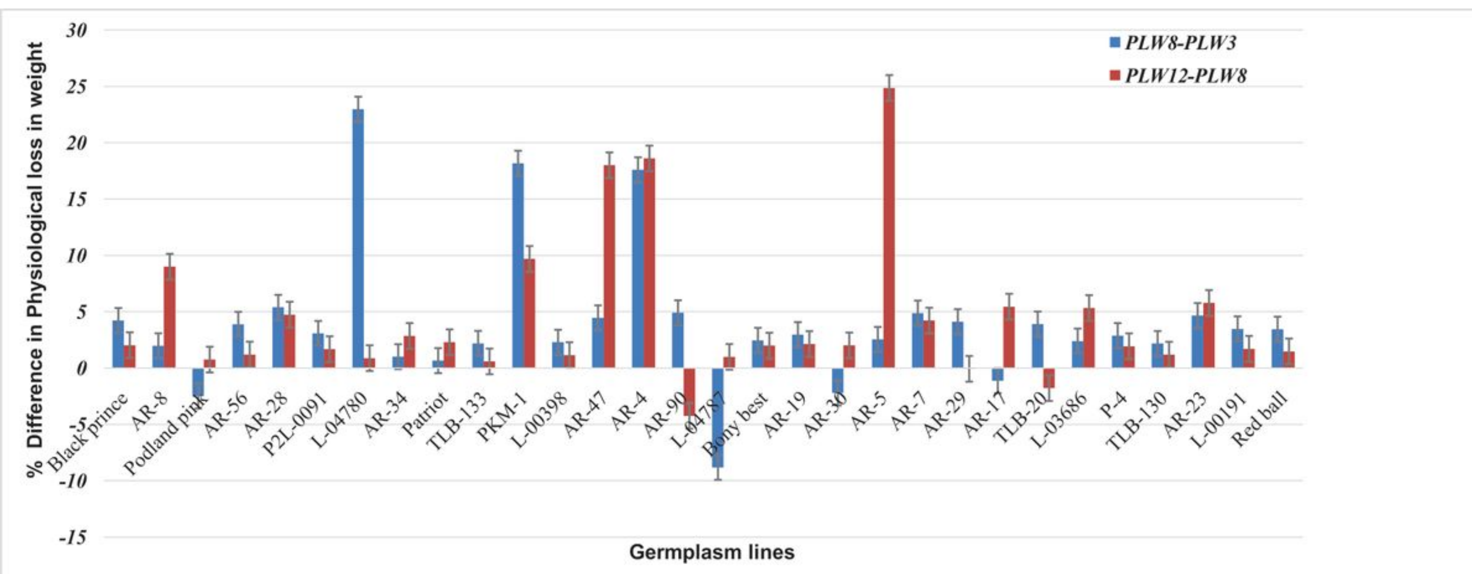

Figure 2

Rate of change in the physiological loss in weight in tomato germplasm lines

Figure 3

Evaluation of tomato germplam lines for shelf life from breakers stage

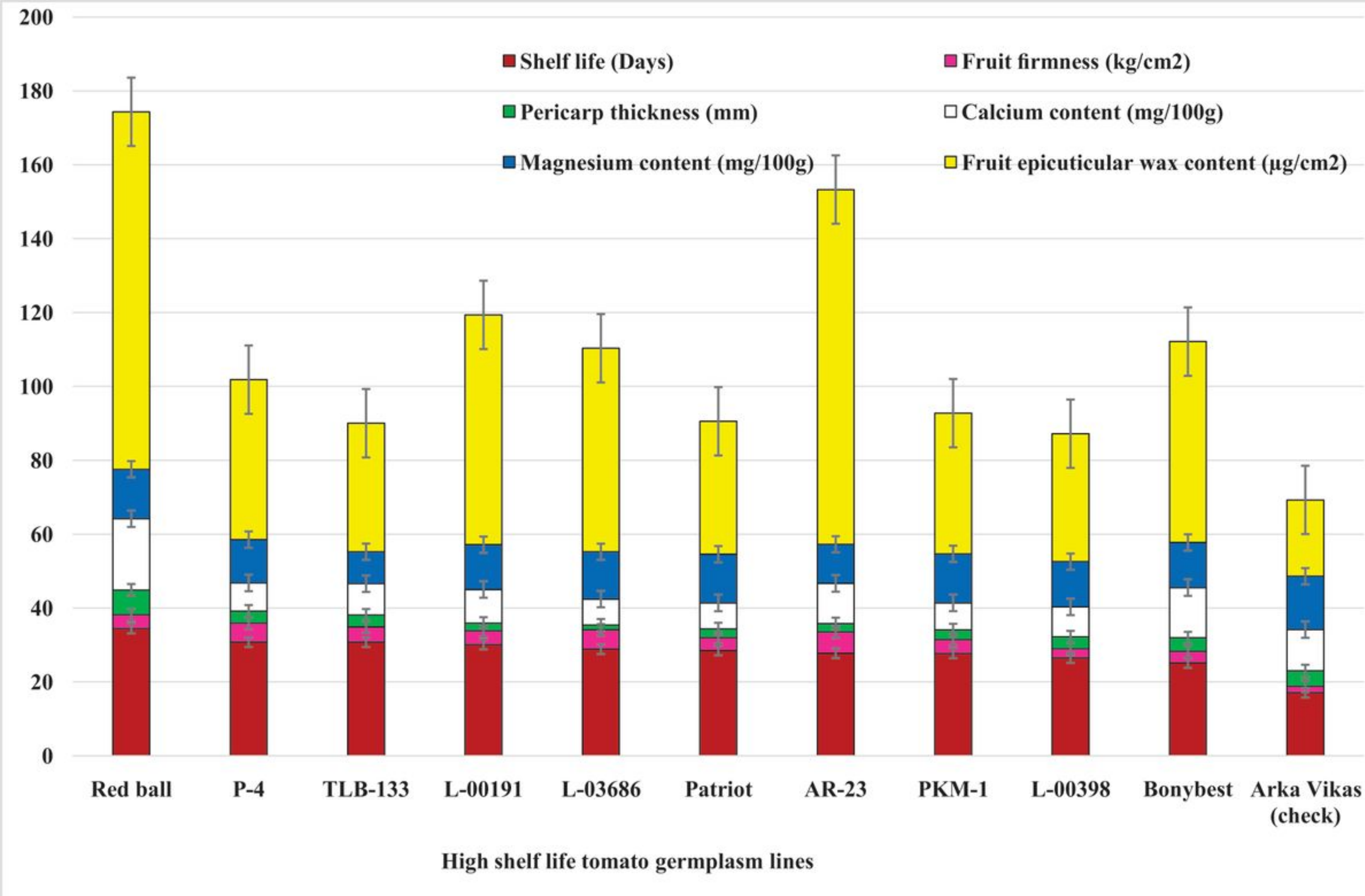

Figure 4

Relative performance of high shelf life tomato germplasm lines with check variety for shelf life and its attributing traits