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Effect of Abiotic Parameters on Vegetable Storability

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

India is the second-largest producer of vegetables. However, vegetables are critical for storage, due to their highly perishable nature, lack of cold storage and transportation facilities. Vegetables get shrivel, whither rapidly, especially under hot conditions, if not preserved just after harvest. The study was conducted at ICAR-IARI to access the effect of abiotic parameters on vegetable quality with time. Effect of abiotic parameters on vegetable storability was studied and statistical analysed results revealed that there was a significant difference (P=0.05) in storage parameters occur when vegetables stored at different temperature and relative humidity. Storability parameters physiological loss in weight (PLW), firmness, colour values and total soluble solids (TSS) of vegetables tomato, spinach, and radish with different temperature and relative humidity were determined. The effect of abiotic parameter i.e. temperature and relative humidity on PLW physiological loss in weight was found significantly different at 5% level of significance. Temperature reduction of 5 – 10°C and RH increment of 10% have a significant effect on quality parameters i.e. PLW, TSS, colour values of vegetables PLW of vegetables and TSS showed an increasing trend with an increase in temperature and decrease in relative humidity. The firmness of tomato and radish showed a decreasing trend with the increase in temperature and decrease in relative humidity but spinach firmness trend was found the opposite. Thus control over these abiotic parameters is essential to retain the quality of the vegetables and prevent their spoilage.

Keywords: Temperature; relative humidity; PLW; firmness; colour; vegetables; storage.

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1. INTRODUCTION

India is the second-largest producer of fruits and vegetables with the production of 81.285 and 162.187 MT, respectively. (NHB, 2015) It is often referred to as a basket of fruit and vegetables. Vegetable contribution out of the total horticultural product is around 60%, whereas its share in the world is nearly 14%. Vegetables and fruits are a major source of nutrients for the human diet. At present in India, nearly 76% of vegetable is consumed as fresh while only 2% is being processed [1].

Vegetables come under the perishable category that is susceptible to damage especially under hot conditions and have a very short shelf life. Contaminations could initiate right from harvest and continues up to its consumption. Unhygienic conditions in transit are the major threat to health due to microbial contamination [2]. Besides this, abiotic factors also adversely affect freshly harvested vegetables, which results in a significant loss in quality as well as quantity (Dadhich et al*.,* 2008). The major abiotic factors affecting the longevity of vegetables are temperature and relative humidity [3]. Higher temperature increases the rate of respiration which, in turn, results in release in moisture and weight loss of vegetables. Liberty [4] reported a 2-3 times increase in the deterioration rate for every 10°C rise in temperature above optimum temperature. The changes that occur during post-harvest operations for vegetables leads to a decrease in their shelf life which, in the long run, leads to a decrease in the quantity supplied for consumption and export market. The common and notable changes that occur during post-harvest in the quality of vegetables include colour changes, loss of weight, and change in the firmness and change in total soluble solids. Several authors [5,6,7,8,9,10,11,12,13,14,15] determined the acceptable firmness and colour values of tomatoes. Firmness and colour are the most important factors for determination of tomato quality. Two possible minimum firmness limits were suggested for tomato fruits at the point of retail marketing and home. All 100% of marketable fruits should have firmness values above 1.45 N mm^{-1} but the Instron values of the tomato at the home use stage should have values higher than 1.28 N mm^{-1}. Minolta a^*/b^* values were less variable for mature green and breaker stages of tomatoes. Separation values between the turning and pink stages were found to be over 0.08 Minolta a^*/b^* value. For the light red stage that is commonly marketable, this was between 0.60 and 0.95. The red stage is a little overripe for normal maturity and its Minolta a^*/b^* values were found to be from 0.95 to 1.21. Islam et al. [12] studied the storage behaviour of tomato inside a zero-energy cool chamber. Tomato fruits were harvested at the accurate stage of maturity and stored inside the zero-energy cool chamber (ZECC) which had a shelf-life of about 7 days at ambient temperature (25ºC). Storing tomato inside the ZECC could be a practical technique at the farmer's field to extend storage life by reducing the quality degradation. Physiological loss in weight (PLW) was faster for fruits held at ambient temperature. Weight loss during the storage at ambient temperature was 5.4%, but untreated fruits at ZECC over the same period showed a 2.6% loss. Although soluble solids increased over the storage period, there were no significant differences between ZECC and ambient temperature. However, the effect of hot water treatment (60ºC for 3 minutes) on quality of tomatoes was visible by increasing storage life up to 29 days. It reduced weight loss and decay, inhibited the colour development and maintained firmness of tomatoes but had no effect on the total content of soluble solids and pH level.

Control over these abiotic parameters is essential for increasing the shelf life of the vegetables and fruits and hence their accurate effect needs to be analysed. Keeping this in mind the study was planned to study the effect of two most influential abiotic factors temperature and relative humidity on storability parameters (PLW, firmness, colour values, and TSS) for vegetables tomato, spinach and radish.

2. MATERIALS AND METHODS

Effect of abiotic parameters i.e. temperature and relative humidity on different vegetable storability was studied. Tomato, radish and spinach representing fruit, root and leafy vegetables were selected for this study. Different combinations of temperature and relative humidity with three different crops were maintained in the plant growth chamber. This was done to obtain the effect temperature and relative humidity on the dependent variables viz., PLW, firmness, colour change and TSS of vegetables. Plan of experiment with factors considered and the levels of variables are presented in Table 1.

Table 1. Plan of the experiment to assess the effect of abiotic parameter on vegetable storability

(a)	Crops	3 (Tomato, Spinach, Radish)	Physiological loss of weight
(b)	Temperatures	3 (20°C, 25°C, 30°C)	(PLW)
(c)	Relative Humidity	2 (70%, 60%)	Firmness
	Replications	3	Colour change
Total treatments (3x3x2x3)		54	Total Soluble Solids (TSS)

2.1 Raw Materials

Raw materials were procured in the morning hours just after harvesting from Pusa Produce sale centre situated in ICAR-IARI. Fresh, uniform-sized, uniform coloured uniformly matured and without any damage or mechanical injury to tomato, spinach and radish were selected for the experiment.

2.2 Plant Growth Chamber

To maintain the specific requirement of temperature and relative humidity plant growth chamber were used. Plant growth chamber (model no. PGW 36) operating on grid power and have temperature control -10 to 45°C (50 to 113°F) with accuracy ± 0.5°C was used. The humidity control ranged from50 to 85%, with an accuracy level of ± 2%. Its volumetric capacity was 6.79 m^3 (240.0 cubic feet). Different combinations of temperature and relative humidity with three different crops were maintained in the plant growth chamber and its effect on vegetable storability was studied.

2.3 Selected Physical Parameters and Their Assessment Techniques

2.3.1 Physiological Loss in Weight (PLW)

Most of the fresh horticultural product contains around 65 to 95% of water at the time of harvest. As the harvested crop loses 10% of its fresh weight, it initiates to wilt and rapidly becomes unusable [16]. Water is an important component of most fruits and vegetables and it adds up to the total weight. A loss of water leads to reduce weight. The loss in weight includes both respiration and evaporation losses, which mainly depends on the temperature and relative humidity of the surrounding air. The PLW was calculated to find the per cent weight loss of the vegetables. Initial and final weights of vegetables were measured by weighing balance with 0.01 gram accuracy. Physiological loss in weight was calculated using the following formula:

$$PLW\,(\%) = \frac{Initial\ mass - Final\ mass}{Initial\ mass} \times 100 \qquad (1)$$

2.3.2 Fruit firmness

Ripening of vegetables and fruits has a direct linkage with firmness. The chemical activity and respiration continue even after harvest. The vegetables and fruits tend to become over-ripe, pale and delicate. When vegetables and fruits are stored at low temperature and high relative humidity, the metabolic activities slow down due to the reduction in the rate of respiration and thus automatically reduces the changes in firmness.

The firmness of tomato and radish was measured by using a texture analyzer (TA-XTplus of Stable MicroSystems, Ltd., Surrey, UK) in compression mode with a 2 mm diameter cylindrical probe (SMS-P/2, Stable Micro Systems, Ltd., Surrey, UK). The operating parameters were: pre-test speed (2.00 mm/s), test speed (1.00 mm/s), post-test speed (10.00 mm/s), and trigger force (5.0 g), distance (5 mm) [17]. Spinach firmness was measured with the same texture analyser by using a 5 mm spherical ball probe to penetrate the leaf at a pre-test speed of 2 mm/s, test speed of 1 mm/s as the probe contacted the leaf and a post-test speed of 10 mm/s. Each leaf was placed between two clamped metal plates with coinciding holes (area of 0.785 m^2) to keep the leaf flat. The probe moved a standard distance of 20 mm. The clearance between the probe and the hole in the plates was 50 mm [18]. Firmness was measured as the maximum force recorded in a force-time curve obtained during the compression of vegetables by the probe. The firmness of vegetables was measured in triplicates and average values were recorded for the study.

2.3.3 Colour changes

The characteristic colour of vegetables is recognized as an essential quality indicator. Colour affects consumer acceptance of a product

Fig. 1. Plant growth chamber model no PGW 36 and texture analyser for firmness measurement

Fig. 2. Hand refractometer, pestle and mortar to measure TSS of vegetables and hunter colorimeter-colour Tec-PCM^{TM} colorimeter

and can account for 40% of the criteria for acceptance. Fruits ripening process continues even after harvesting which could be an important factor to be noted during post-harvest operations. The colour changes were based on the physical appearance of the fruits and vegetables. The surface colour of vegetables was measured by using Hunter colourimeter, Colour Tec-PCM^{TM} Colorimeter (Accuracy Microsensors 30 mm, Tokyo, Japan). Where colour is expressed in CIE lab tristimulus values (L, a, b) values, (L*) defines lightness, (a*) denotes the red/green value and (b*) the yellow/blue value. The colour was measured in three places of each sample and average values were recorded for the study. Before measuring, the colourimeter was standardized with white and black calibration tiles provided with the instrument. Colour difference values (ΔE) were calculated according to Checmarev et al. [19] the following formula:

$$\text{Colour change } (\Delta E) = \sqrt{\Delta L*^2 + \Delta a*^2 + \Delta b*^2} \quad (2)$$

2.3.4 Total Soluble Solid (TSS)

Change in total soluble solid occurs during ripening. Carbohydrate is broken down into a simpler unit i.e. the conversion of starch to sugar, giving the product its characteristics sweet taste on ripening. The degree of ripening can be measured by measuring the sugar content in an extracted fruit juice [20]. The total soluble solids (TSS) was determined by following the procedures described by Seyoum et al., [21]. The TSS was determined by hand refractometer (Model Misco) with a range of 0 to 32 °Brix and a resolution of 0.2°Brix. The refractometer was standardized against distilled water (0°Brix TSS). The juice was extracted using a pestle and mortar and by placing 1 to 2 drops of clear juice on the prism. Between samples, the prism of the refractometer was washed with distilled water and dried before use. The results were expressed as degree brix (ºB) at 20ºC.

3. RESULTS AND DISCUSSION

Storability study of vegetables namely tomato, spinach and radish; representatives of fruit, leafy

and root vegetables respectively were conducted in the controlled condition. Different combinations of temperature and relative humidity were studied in the Plant Growth Chamber. The effects of abiotic parameters on vegetable storability are presented below.

3.1 Physiological Loss in Weight (PLW)

The total weight of vegetables decreased due to physiological stress when stored for a long period. Physiological weight loss of vegetables stored in controlled condition at different temperature and relative combinations are presented in Figs. 3, 4 and 5. There was a considerable effect on physiological loss in weight at different temperature and relative humidity. It was observed that PLW had an increasing trend with an increase in temperature and decreasing trend with an increase in relative humidity. PLW (%) of tomato on 8th day of storage, at temperature and RH combinations 20°/70%, 25°/70%, 30°/70% were found as 4.47%, 6.48%, 9.01% respectively. While at temperature and RH combinations 20°/60%, 25°/60%, 30°/60% were found as 5.80%, 8.01% and 11.96% respectively (Fig. 3).

Physiological weight loss PLW (%) of Radish with leaves at 6th day of storage, at temperature(°C) and RH (%) combinations 20°/70%, 25°/70%, 30°/70% were 7.67%, 9.46%, 11.61% respectively. While at temperature and RH combinations 20°/60%, 25°/60%, 30°/60% were 8.72%, 10.83% and 13.22% respectively (Fig. 4).

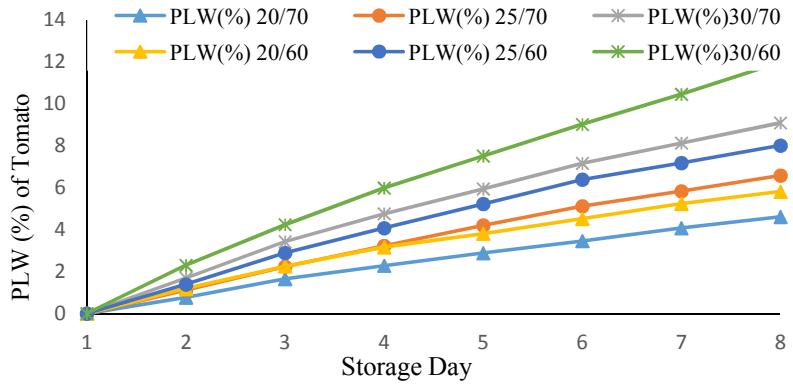

Fig. 3. Effect of temperature and relative humidity combinations on PLW of tomato stored in controlled condition

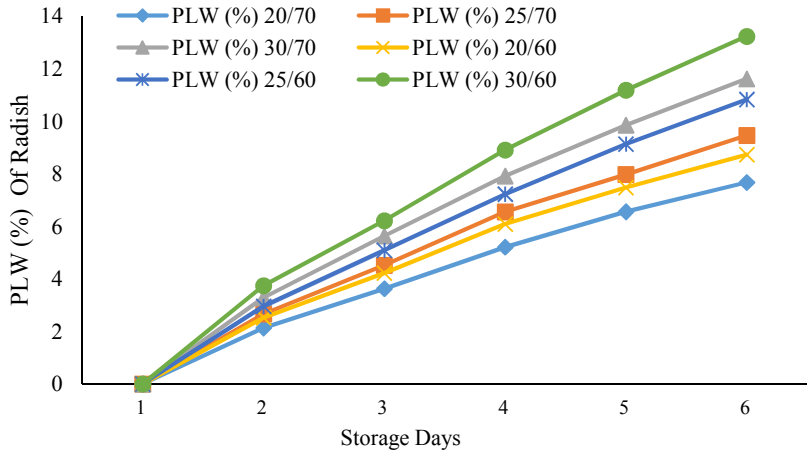

Fig. 4. Effect of temperature and relative humidity on PLW of radish stored in controlled condition

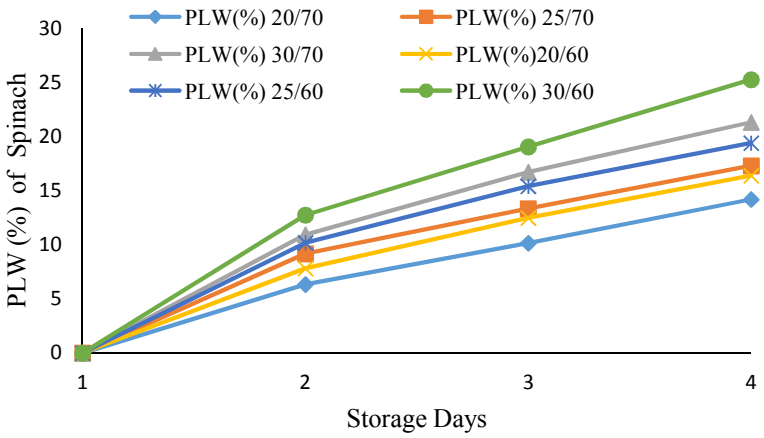

Fig. 5. Effect of temperature and relative humidity on PLW of spinach stored in controlled condition

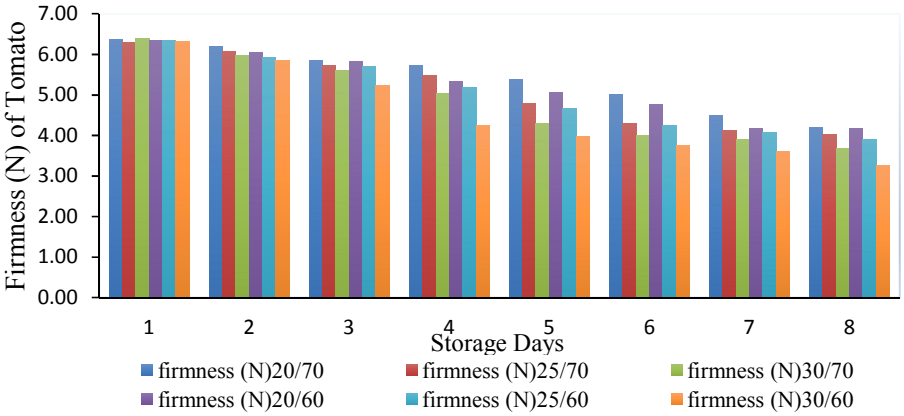

Fig. 6. Effect of temperature and relative humidity on the firmness of tomato stored in controlled condition

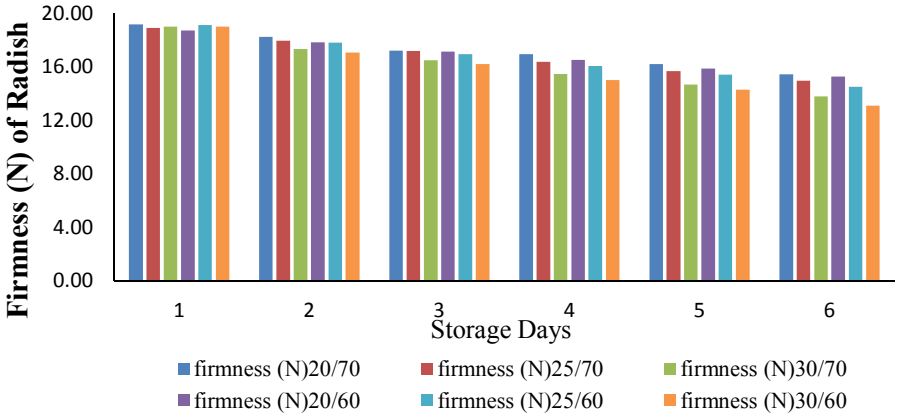

Fig. 7. Effect of temperature and relative humidity on the firmness of radish stored in controlled condition

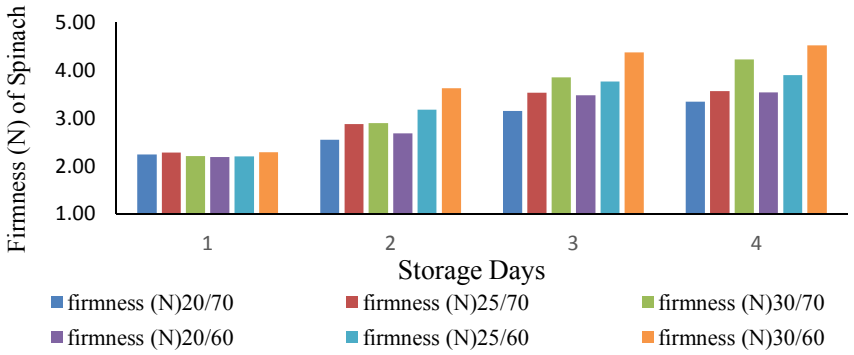

Fig. 8. Effect of temperature and relative humidity on the firmness of spinach stored in controlled condition

The PLW (%) of spinach on 4th day of storage, at temperature and RH combinations 20°/70%, 25°/70%, 30°/70% were found as 14.19%, 17.19%, 21.23% respectively. While at temperature and RH combinations 20°/60%, 25°/60%, 30°/60% were found as 16.38%, 19.39% and 25.25% respectively (Fig. 5). A similar trend was reported by Mogaji and Fapetu, [22]. From the analysis of variance, it was observed that the PLW of tomato, spinach and radish at different temperature and relative humidity was significantly different at 5% level of significance (Tables 1 and 2). The PLW of tomato varied lesser than leafy vegetables like spinach, this may be due to more loss of moisture content and high respiration rate in spinach. We observed that a 5°C increase or decrease in temperature and 10% increase or decrease in relative humidity had a considerable effect on the PLW of vegetables.

3.2 Firmness

Firmness is one of the important parameters which affects product quality and is related to consumer acceptance as *it* is used by consumers as an indicator of high-quality products. The firmness of tomato, spinach and radish stored at different temperature and relative humidity were determined and represented in Figs. 6, 7 and 8.

The firmness of tomato on 8th day of storage at temperature and RH combinations 20°/70%, 25°/70%, 30°/70% were found as 4.21 N, 4.02 N and 3.68 N respectively. Similarly the firmness for tomato stored at temperature and RH combinations 20°/60%, 25°/60%, 30°/60% were found as 4.17 N, 3.89 N, 3.27 N respectively (Fig. 6). At the same time firmness of radish on 6th day of storage at temperature and RH. combinations 20°/70%, 25°/70%, 30°/70%, 20°/60%, 25°/60%, 30°/60% was observed as 15.42 N, 15.28 N, 13.79 N, 15.24 N, 14.49, and 13.09 N respectively (Fig. 6). Similar trend results of radish firmness were obtained by Zhang et al., [17]. The firmness of tomato and radish decreased with increase in temperature and decrease in relative humidity. It was observed that the firmness of tomato and radish varied lesser with RH but higher with temperature. Spinach firmness increased with increase in temperature and decrease in relative humidity this may be due to the moisture loss from leaves. For spinach opposite trend that of tomato and radish was observed. Similar results for spinach firmness were reported by More et al., [18]. The data on fruit firmness revealed that the firmness of tomato, spinach and radish during storage period was significantly affected by the different treatments. Similar trend results were reported by Mansuri [23]; Lana et al., [10]. From the analysis of variance, it was observed that the firmness of tomato, spinach and radish at different temperature was significantly different at 5% level of significance. The firmness of tomato and radish was not significantly different at different relative humidity at 5% level of significance but significantly different for spinach (Tables 1 and 2).

3.3 Total Soluble Solid (TSS)

The total soluble solid of the product indicates the sugar content and ripening of produce. The variation in TSS with different temperature and relative humidity combinations of tomato, radish and spinach presented in Figs. 8, 9 and 10. Results revealed that TSS increased with increase in temperature and decrease in relative humidity with increasing storage period. The result indicated that the tomato TSS varied from

4 - 6°Brix up to 8th day of storage and the TSS of radish and spinach varied from 4–8°Brix. Up to end of self-life. A similar trend was reported by Seyoum et al., [21]. From the analysis of variance, it was observed that the TSS of tomato spinach and radish at different temperature and relative humidity was significantly different at 5% level of significance (Tables 3 and 4).

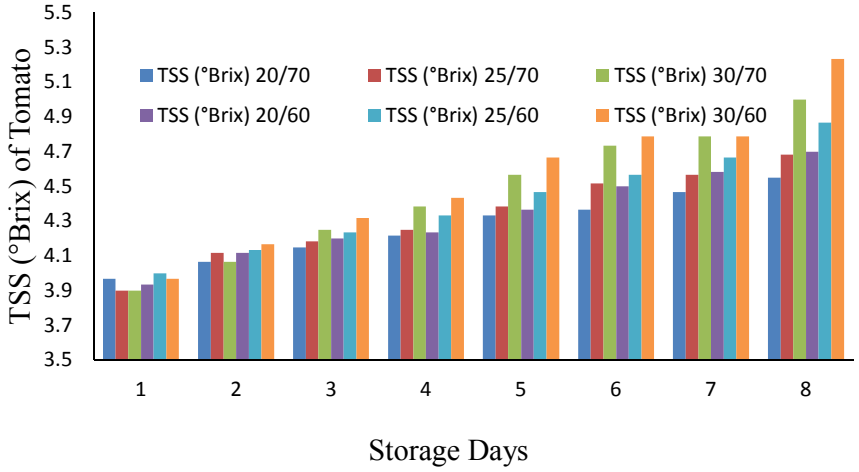

Fig. 9. Effect of temperature and relative humidity on TSS of tomato stored in controlled condition

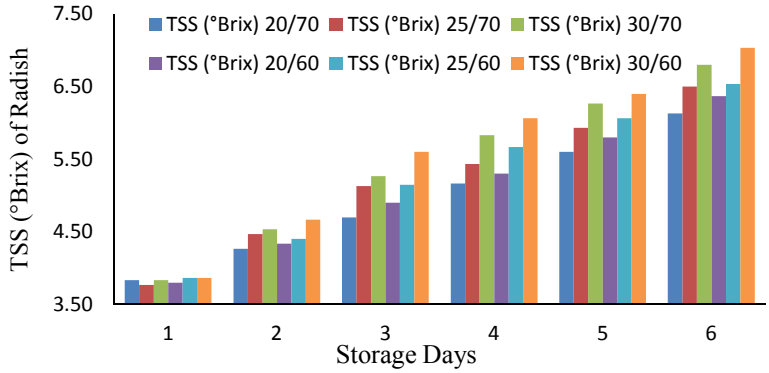

Fig. 10. Effect of temperature and relative humidity on TSS of radish stored in controlled condition

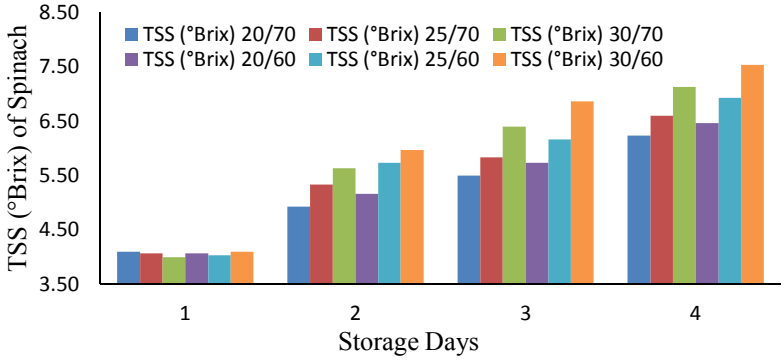

Fig. 11. Effect of temperature and relative humidity on TSS of spinach stored in controlled condition

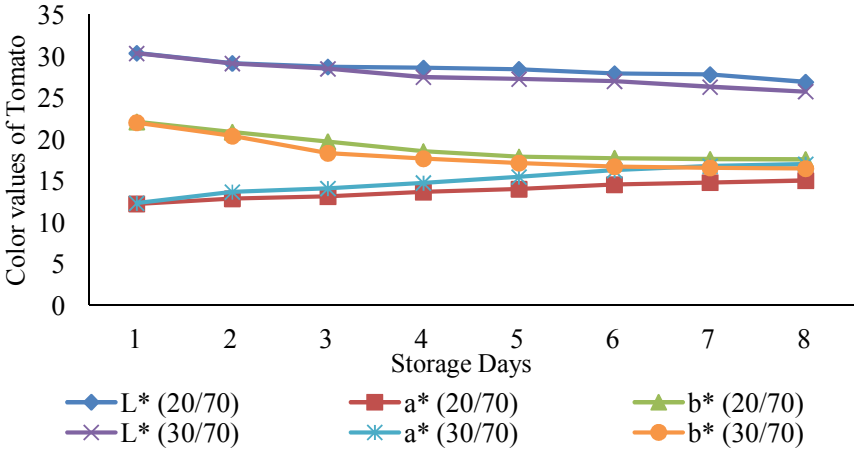

Fig. 12. Effect of temperature and relative humidity on colour values of tomato stored in controlled condition

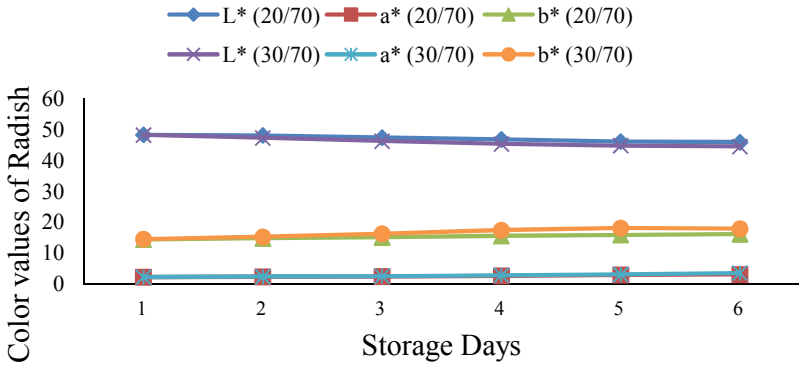

Fig. 13. Effect of temperature and relative humidity on colour values of radish stored in controlled condition

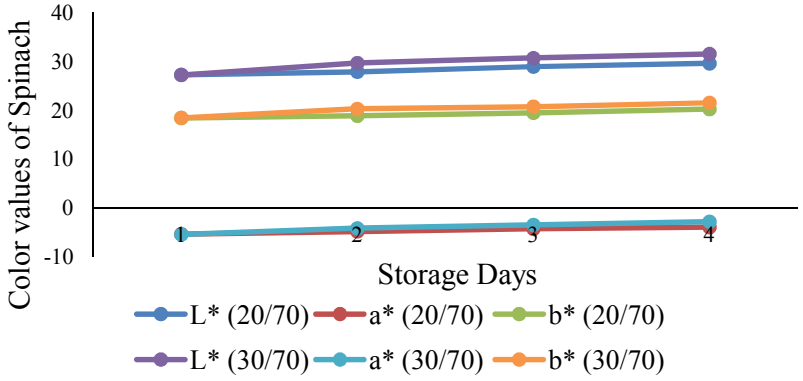

Fig. 14. Effect of temperature and relative humidity on colour values of spinach stored in controlled condition

Table 2. Analysis of the effect of temperature on physiological weight loss (PLW %) and firmness (N)

Sr. no	Crop / Temp.	Tomato PLW	Radish PLW	Spinach PLW	Tomato firmness	Radish firmness	Spinach firmness
1	20	5.20[c]	8.28[c]	14.65[c]	4.19[a]	15.32[a]	3.82[b]
2	25	7.29[b]	10.20[b]	18.49[b]	3.95[a]	14.72[b]	3.75[b]
3	30	10.52[a]	12.43[c]	23.37[a]	3.44[b]	13.44[c]	4.39[a]
Pr > F		<0.0001	<0.001	<0.001	0.0008	<0.0001	<0.001

Table 3. Analysis of effect of relative humidity on physiological weight loss (PLW %) and firmness (N)

Sr. no	Crop / RH	Tomato PLW	Radish PLW	Spinach PLW	Tomato firmness	Radish firmness	Spinach firmness
1	70	6.75[b]	9.66[b]	17.04[a]	3.97[a]	14.72[a]	3.81[b]
2	60	8.59[a]	10.95[a]	20.63[a]	3.75[a]	14.27[a]	4.15[a]
Pr>F		<0.0001	<0.0001	<0.0001	0.09	0.06	<0.0001

**Means with the different letter are significantly different*

Table 4. Analysis of the effect of temperature on TSS (°Brix)

Sr. no	Crop / Temp.	Tomato TSS	Radish TSS	Spinach TSS
1	20	4.60[c]	6.52[c]	6.35[c]
2	25	4.77[b]	6.52[b]	6.76[b]
3	30	5.11[a]	6.91[a]	7.33[a]
Pr > F		<0.0001	0.0005	<0.0001

**Means with the different letter are significantly different*

Table 5. Analysis of the effect of relative humidity on TSS (°Brix)

Sr. no	Crop / RH	Tomato TSS	Radish TSS	Spinach TSS
1	70	4.75[b]	6.47[b]	6.65[b]
2	60	4.94[a]	6.65[a]	6.97[a]
Pr > F		<0.001	<0.0001	<0.001

**Means with the different letter are significantly different*

3.4 Colour Change

Colour is the main factor considered by consumers in quality assessment of fruits. Colour value L*, a*, and b* were measured throughout the storage period and results of colour values of tomato, radish and spinach are shown in Figs. 10, 11 and 12 respectively. Result revealed that colour is a function of storage time, relative humidity and temperature. As the storage period and temperature increased colour values also changes indicating a change in colour. In the case of tomato L* value decreased slightly which indicates that lightness of tomato decreased and it's becoming darker. The increased a* component value indicates an increase in redness of tomato, while decreased b* value indicates a decrease in yellowness of tomato. At temperature 20°C and 30°C observed some variations in L*, a*, and b* values showed a change in the colour of tomato with the change in temperature. A similar trend of colour values for tomato was reported by Khairi et al. [24].

In the case of radish, a* values did not change extensively but, b* value increased and L* value decreased which revealed an increase in yellowness of radish and decrease in the whiteness of radish. At temperature 20°C and 30°C observed little variations in L*, a*, and b* values showed little change in colour of radish with temperature change. For spinach increment in b* and L* values was observed because of the appearance of an increase in yellowness of the

spinach, while the change in a* value from -5 to -3 showed a decrease in greenness. The L*, a* and b* values of spinach changed as storage temperature changed, which indicated that temperature had a considerable effect on the colour of spinach.

4. CONCLUSION

The study was undertaken to develop a green energy-based vegetable transit storage unit. In the present study, the effect of abiotic parameters on vegetable storability was studied. Storability study of three vegetables namely tomato, spinach and radish representatives of fruit, leafy and root vegetables were conducted in controlled condition. Different combinations of temperature and relative humidity controlled in Plant Growth Chamber. Their effects on storability were assessed. The parameters included for assessment of storability study were physiological loss in weight (PLW %), colour change, firmness and total soluble solids (TSS). Experimental results were statistically analysed. Storability parameters PLW, firmness, colour values, and TSS of vegetables tomato, spinach, and radish with different temperature and relative humidity were determined. The effect of abiotic parameter i.e. temperature and relative humidity on PLW physiological loss in weight was found significantly different at 5% level of significance. Temperature reduction of 5 – 10°C and RH increment of 10% have a significant effect on quality parameters i.e. PLW, TSS, colour values of vegetables PLW of vegetables and TSS showed an increasing trend with an increase in temperature and decrease in relative humidity. The firmness of tomato and radish showed a decreasing trend with the increase in temperature and decrease in relative humidity but spinach firmness trend was found the opposite.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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