Agric Res J **60** (3) : 460-466, *June* 2023
DOI No. 10.5958/2395-146X.2023.00067.4

RESPIRATION RATE AND HEAT OF RESPIRATION OF GREEN CHILLI (*Capsicum annuum* L.) AS INFLUENCED BY STORAGE HUMIDITY AND TEMPERATURE

Bhaumik B Patel* and Roy F Sutar

Department of Post Harvest Engineering and Technology, Anand Agricultural University, Anand - 388110, Gujarat

ABSTRACT

Green chilli (*Capsicum annuum* L.) being a perishable product, the present study was undertaken to investigate the influence of storage humidity and temperature on its respiration rateand heat of respiration. Fully automated air tight multi-chamber temperature and humidity control system was used to determine respiration rate of green chilli at different temperatures (5, 10, 15, 20 and 25°C) and relative humidity (80 and 90%). Respiration rate of the green chilli decreased significantly with the time during the storage under predetermined conditions.Increased storage temperature significantly increased respiration rate of the green chilli. However, high humidity reduced the respiration rate and thereby heat of respiration of green chilli. For all storage temperatures (5-25°C) after one hour of storage of green chilli,lower respiration rates were recorded at 90% RH compared to 80% RH.Moreover, from Arrhenius-based respiration model it was noted that the green chilli was more sensitive to storage temperature at 90% RH compared to 80% RH. Hence, it is concluded that longer shelf life is possible at 90% RH.

Keywords: Green chilli, Heat of respiration, Multi-chamber system, Respiration rate

Green chilli (*Capsicum annuum* L.), a tropical and sub-tropical spice vegetableis a rich source of vitamin C, A and B (Saxena *et al*., 2016). Chilli,belongs to the *Solanaceae* familyand is economically one of the most important commercial crops of India. In 2021-22, green chill production was 42,20,720 MT in India (Anonymous, 2023).However, the annual post-harvest losses in chilli is 5.6% i.e., 3.9% in farm operations and 1.7% in storage, having an estimated value of 547 crore INR (Jha *et al.,* 2015). The storage losses are mainly due to respiration and transpiration of the produce which affect its freshness and quality. Respiration is an oxidative metabolism in which reserves, mainly sugar and fatty acids present in the fruit and vegetable cells are consumed along with oxygen present in the air. This process, as shown in the following chemical reaction generates heat and carbon dioxide and water losses from the produce. $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O +$ energy

The optimal post-harvest life of fresh produce requires slowing down and control of this physiological process. The controlled respiration rate of fresh produce after harvest contributes to the retention of its quality and extend the shelf life and hence reduces losses to producers. However, factors such as storage temperature and humidity, environmental gas composition, time elapsed from the harvest and a volume of enzymeand substrate in the cellular solution affects respiration rate of fresh produce (Uchino *et al*., 2004).Accordingly, in addition to the basic post-harvest technologies for temperature management, an array of others has been developed, including various physical (heat, irradiation and edible coatings); chemical (antimicrobials, antioxidants and anti-browning); and gaseous treatments (CA, MA and Ultra-low O_2) to extend the storage life of fruits and vegetables (Mahajan *et al.*, 2014). Although, the effectiveness of these technologies depends on the respiratory response of the stored produce to storage conditions.

Few studies were conducted by different scientists to determine the rate of respiration of green chilli at various temperatures, the time since harvest and under different gas compositions. Chaturani *et al*. (2004) investigated the effect of different stages of maturity, rangingfrom light green to full red on the respiration of green chilli. Jansasithorn *et al*. (2010) examined varietal difference in the respiration rate of three green chilli cultivars. Hameed *et al*. (2013) determined rate of respiration of green chilli after 3 weeks of storage at 0, 5, 10 and 15°C. Azlin *et al*. (2014) investigated respiration of green chill as affected by preconditioning treatments. Furthermore, influence of modified atmosphere packaging on the rate of respiration of green chilli was assessed by Chitravathi *et al*. (2015).

Maskey *et al.* (2021) reported that storage of hydrocooled Akabare chillies at room temperature (25–27°C) resulted in high weight loss and rapid deterioration in vitamin C and chlorophyll change as

*Corresponding author : patel13_13@live.com
Date of receipt: 03.05.2023, Date of acceptance: 30.06.2023

compared to refrigerated temperature (8–10°C) storage having relative humidity 70–75%. Ul Hasan *et al*. (2021) noted that green chilli is susceptible to high moisture loss, wrinkling, and rapid degradation of green color after harvesting. Though, till date, no studies have been reported on the respiratory behaviour of green chilli at various humidity and temperature combinations. Therefore, during storage of green chilli along with the temperature, relative humidity has a significant effect on its quality. Hence, the objective of the present study was to determine the respiration rate of green chilli as a function of storage humidity and temperature under static condition.The respiration rates thus obtained would be helpful for designing of appropriate storage environments for obtaining longer shelf life.

MATERIALS AND METHODS

Raw material

To conduct the experiments, green chilli of *cv.* 'Clause HP 158 F1' were procured from the local farmer of Anand district. Fully matured, uniform sized green chilli free from spoilage, infestation and external injuries were picked from the field in the early morning. Then, harvested green chilli were brought to the Department of Post Harvest Engineering and Technology, College of Food Processing Technology and Bio-Energy for further studies.

Estimation of physico-chemical properties of green chilli

Physico-chemical properties viz., length, diameter, weight, density, total soluble solids, pH and acidity of twenty green chillies were measured as the methods described by Patel *et al*. (2015).From the physical properties of the chilli, its quantity that could be accommodated in the system was estimated, whereas chemical properties indicated its quality.

Respiration rate of green chilli

Unique automated air tight multi-chamber temperature and humidity control system as described by Patel *et al*. (2016) was used with modification to determine respiration rate of green chilli at different storage conditions (temperature and humidity). The developed system consists of 10 chambers in which 9 chambers are equipped with auto control system to maintain different temperature and humidity individually as per requirement and remaining one was used for control without any set condition. All chambers are of the same capacity of 45 Land provided with a perforated sample tray, fixed on a load-cell. An opening of 200 mm diameter is designed with an airtight lid to place or remove the sample. Indigenous auto-gas sampling device has been developed to facilitate measurement of the change in gas composition of the storage environment of each chamber. It has a suction and flushing pump, and gas sample holding box. The gas sample obtained from each chamber was stored in the gas sample holding box where concentrations of carbon dioxide and oxygen gases were detected by gas sensors fitted in the gas sample holding box. The measured data were transferred to a data-logger connected to gas sensors and load-cell at predetermined time interval.

For the experimental trials, each chamber of the developed system was maintained at different temperatures (5, 10, 15, 20 and 25°C) and relative humidity (80 and 90%)along with control (ambient condition). Green chilli obtained from the field were divided into 2 kg lots and immediately placed in the air tight multi-chamber temperature and humidity control system at pre-set temperature and humidity. Then, the chambers were closed with air tight lids. Gas sampling from the chambers was carried out at 1 h intervals using auto-gas sampling system to measure the amount of carbon dioxide evolved and oxygen consumed due to respiration. Rate of respiration (RR_{CO2}) was calculated at one hour from the change in carbon dioxide concentration as per eq. 1 (Patel *et al*., 2016).

$$RR_{CO2}\ (mLCO_2.kg^{-1}.h^{-1}) = \frac{(C^F_{CO_2} - C^I_{CO_2}) \times P_V}{W_S \times \Delta t} \quad .\ (1)$$

Where;

$C^I co_2$ = Initial concentration of CO_2, mL

$C^F co_2$= Final concentration of CO_2, mL

P_V = Partial volume in headspace, mL

W_S = Weight of sample, kg

Δt = Enclosed time interval, h

Heat of respiration of green chilli

Respiration, a catabolic process, takes up 1.067 mg of $O_2$to metabolise 1.0 mg of glucose and 1.467 mg ofCO_2, 0.60 mg of H_2O, and 15.6kJ of heat are produced. Accordingly, 1 mg of CO_2 production results into 2.55 cal heat energy. Therefore, release of 61.2 kcal.metric ton^{-1}.day^{-1} heat energy represents 1 mgCO_2.kg^{-1}.h^{-1} respiration rate of the produce and heat of respiration (HR)can be calculated as per eq. 2 (Patel *et al*., 2016).

$$HR\ (kcal.ton^{-1}.day^{-1}) = RR_{CO2} \times 61.2 \quad \ldots..\ (2)$$

Where,

RR_{CO2} = Rate of respiration, mgCO_2.kg^{-1}.h^{-1}

Modelling of respiration rate of green chilli

Modelling of the respiration rate of green chilli was conducted using the Arrhenius equation (eq. 3; Jansasithorn *et al*., 2010). The magnitudes of respiration rate constants are established by measuring carbon dioxide gas concentration as a function of temperature under controlled conditions for the modelling of the respiration rate (RR_{CO2}) of the green chilli. These investigations resulted in the quantification of activation energy for respiration in green chillito provide insight on the relative impact of temperature on its respiration under each relative humidity.

$$RR_{CO2} = A \exp^{\left[\frac{-E_a}{RT}\right]} \quad \text{..... (3)}$$

Where,

RR_{CO2} = Rate of respiration, $mmolCO_2.kg^{-1}.h^{-1}$

A = Pre-exponential factor, $mmolCO_2.kg^{-1}.h^{-1}$

Ea = Apparent activation energy, $J.mol^{-1}$

R = Ideal gas constant = 8.314 $J.mol^{-1}.K^{-1}$

The apparent activation energy (Ea) and pre-exponential factor (A) were determined from the slope and intercept given by a linear regression of ln (RR_{CO2}) vs. (1/T) at each individual measurement for each storage humidity. An ANOVA was conducted to compare the Ea from each storage humidity with a least significant difference test at P = 0.05.

Statistical analysis

Experimental data on respiration rate and heat of respiration of green chilli, obtained from three replications were statistically analysed using factorial completely randomized design (F-CRD) using Design-Expert version 7.0.0 (Stat-Ease Inc., Minneapolis, USA) software. ANOVA tables were prepared to understand the influence of storage temperature, relative humidity and time on respiratory behaviour and heat of respiration of green chilli at 5% significance level.

RESULTS AND DISCUSSION

Physico-chemical properties of green chilli

Freshly harvested green chilli were analysed to determine its physico-chemical properties such as length and diameter, weight of a fruit, density, pH, total soluble solid, titratable acidity and moisture content. Mean values of the physico-chemical properties of green chilli obtained are reported in Table 1. It was estimated that 2 kg of sample could be accommodated in the system considering adequate space for the circulation of air to maintain desire temperature and humidity.

Table 1. Physico-chemical properties of green chilli

Property		Mean±SD
Physical	Length (mm)	97.65±2.53
	Diameter (mm)	24.09±2.61
	Density ($kg.m^{-3}$)	467±19.60
	Weight of single fruit (g)	24.23±2.01
Chemical	pH	6.20±0.01
	Acidity (%)	0.0896±0.02
	TSS (°B)	4.35±0.35
	Moisture (%wb)	89.9±0.29

All values are mean values of twenty replications

Rate of respiration of green chilli under steady state condition

Respiration rate of green chilli was measured for various combinations of temperature and RH over a period of time and the data are depicted in Fig. 1, and was observed to decrease under all storage conditions. However, as the storage temperature increased from 5 to 25°C, the rate of respiration increased significantly ($p \le 0.05$) from 12.61 to 52.08 $mLCO_2.kg^{-1}.h^{-1}$ and 4.35 to 30.71$mLCO_2.kg^{-1}.h^{-1}$at 80 and 90% RH after one hour, respectively (Fig. 2). Thus, at high temperature green chilli respired at a faster rate due to rapid breakdown of carbohydrates and other complex organic compounds (Patel *et al*., 2016). In contrast, a decrease in the respiration rate of green chilli was recorded with an increase in humidity. At high relative humidity (90%) there was less moisture loss (0-0.33% at 5 to 25°C) from the stored produce which aids to low respiration rate, whereas low RH accelerated the

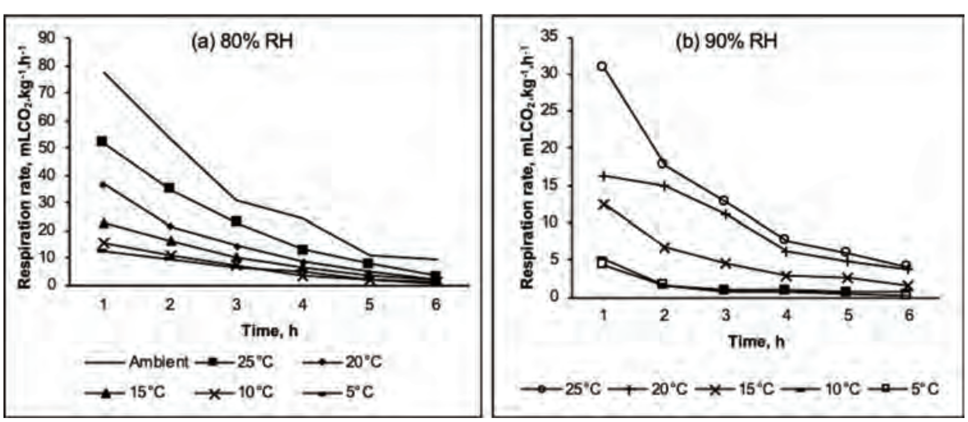

Fig. 1. Respiration rate of green chilli at different temperature and (a) 80% RH and (b) 90% RH over a period of time

Table 2. ANOVA for respiration rate of green chilli under different storage conditions with time

Source of variation	df	SS	MS	F Value	Prob>F		% Contribution
A-Temp.	4	4982.40	1245.60	< 0.0001	3168.69	*	27.23
B-Time	5	7588.26	1517.65	< 0.0001	3860.77	*	41.47
C-RH	1	1638.82	1638.82	< 0.0001	4169.01	*	8.96
AB	20	2548.40	127.42	< 0.0001	324.14	*	13.93
AC	4	129.61	32.40	< 0.0001	82.43	*	0.71
BC	5	1107.15	221.43	< 0.0001	563.30	*	6.05
ABC	20	256.82	12.84	< 0.0001	32.67	*	1.40
Error	120	47.17	0.39				0.26
S.Em.				AxBxC = 0.36			
CD (p≤0.05)				AxBxC = 1.01			
CV (%)				5.72			

*Indicates the significant effect at 95% confidence level (p≤ 0.05)

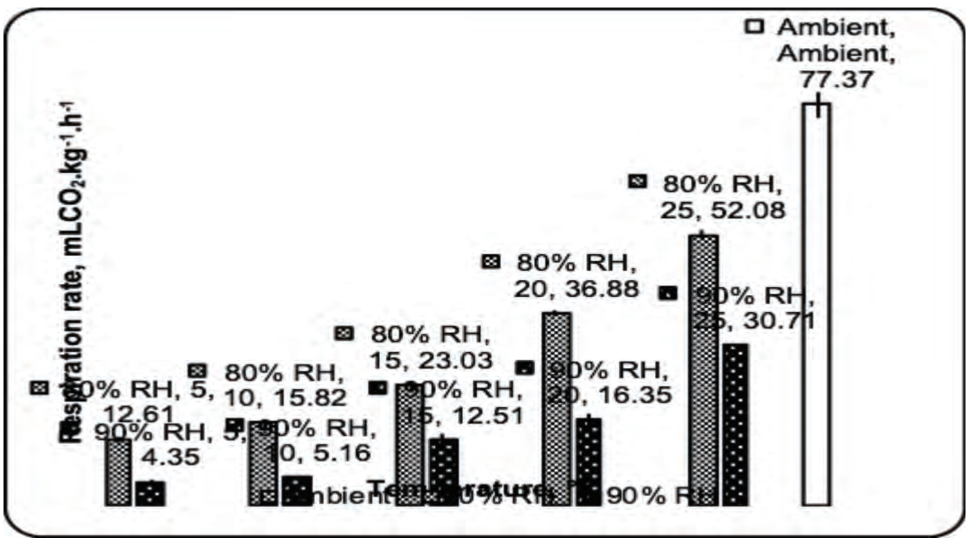

Fig. 2. Respiration rate of green chilli after one hour storage

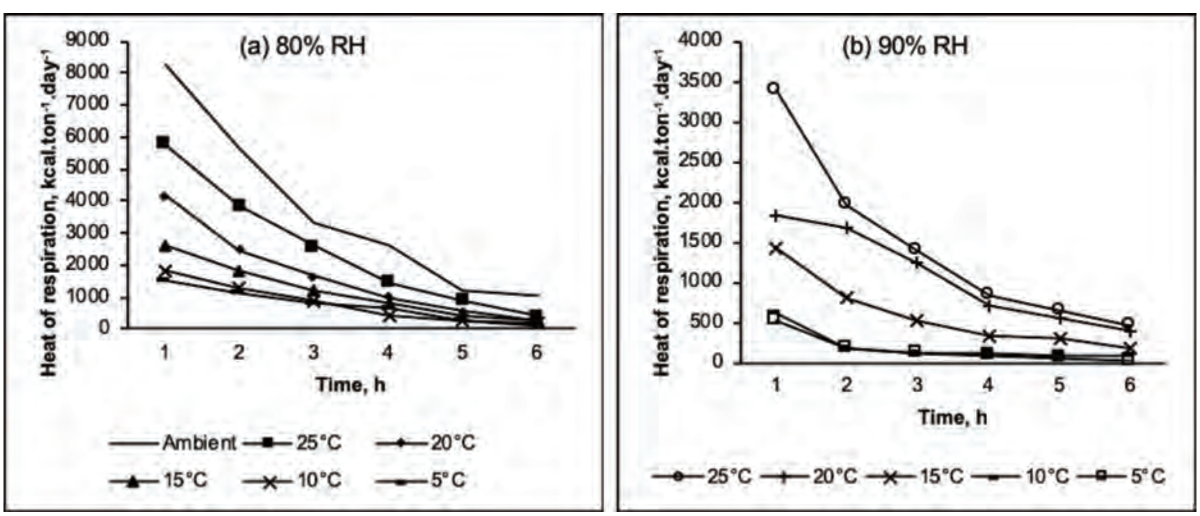

Fig. 3. Heat of respiration of green chilli at different temperature and (a) 80% RH and (b) 90% RH over a period of time

Table 3. ANOVA for heat of respiration of green chilli under different storage conditions with time

Source of variation	df	SS	MS	F Value	Prob>F		% Contribution
A-Temp.	4	58944502	14736125	< 0.0001	2912.29	*	26.00
B-Time	5	96977313	19395463	< 0.0001	3833.11	*	42.78
C-RH	1	21305248	21305248	< 0.0001	4210.54	*	9.40
AB	20	30111627	1505581	< 0.0001	297.55	*	13.28
AC	4	1409720	352430	< 0.0001	69.65	*	0.62
BC	5	14277853	2855571	< 0.0001	564.34	*	6.30
ABC	20	3055425	152771	< 0.0001	30.19	*	1.35
Error	120	607197	5060				0.27
S.Em.				AxBxC = 41.07			
CD ($p\leq0.05$)				AxBxC = 114.65			
CV (%)				5.76			

*Indicates the significant effect at 95% confidence level ($p\leq0.05$)

moisture migration from the green chilli i.e., 0-0.77% as the storage temperature increased from 5 to 25°C. Accordingly, Wilkinson (1970) attributed this behaviour to diminished gas exchange with increasing moisture loss. Furthermore, Mann (1954) has observed that fruit at 3°C in an80% RH had more than double weight loss due to water evaporation than in a 90% RH at the same temperature in a week. Similar trend was observed by Raza *et al.* (2013) for mango. Jansasithorn *et al*. (2010) demonstrated that the respiration rate of a paprika cultivar of green chilli increased from 0.15 mmolCO_2.kg^{-1}.h^{-1}(3.41mLCO_2.kg^{-1}.h^{-1}) at 0°C to 2.20 mmolCO_2.kg^{-1}.h^{-1}(53.61mLCO_2.kg^{-1}.h^{-1}) at 20°C. Green chilli respiration rate remained high (77.37 mLCO_2.kg^{-1}.h^{-1}) at ambient storage compared to other storage conditions. From the ANOVA test of the categoric factors viz., storage temperature, humidity and time as shown in Table 2, it was found that linear and interaction effects of all factors had a significant ($p\leq0.05$) effect on the rate of respiration under steady state condition. Among the storage factors, storage time had a most significant impact on respiration rate of green chilli followed by temperature and humidity.

Heat of respiration of green chilli under steady state condition

Heat generated due to the respiration of the green chilli during storage contributes to heat load on the refrigeration system. Heat of respiration of the regionally grown variety of the green chilli was estimated from the rate of respiration for different storage conditions and results obtained are presented in Fig. 3. The heat of respiration is observed to be proportional to the rate of respiration, and decreased with time, increased with an increase in temperature and decreased with an increase in humidity. After one hour storage of green chilli under different storage conditions, heat of respiration varied from 1497.62 to 5762.63 kcal.ton^{-1}.

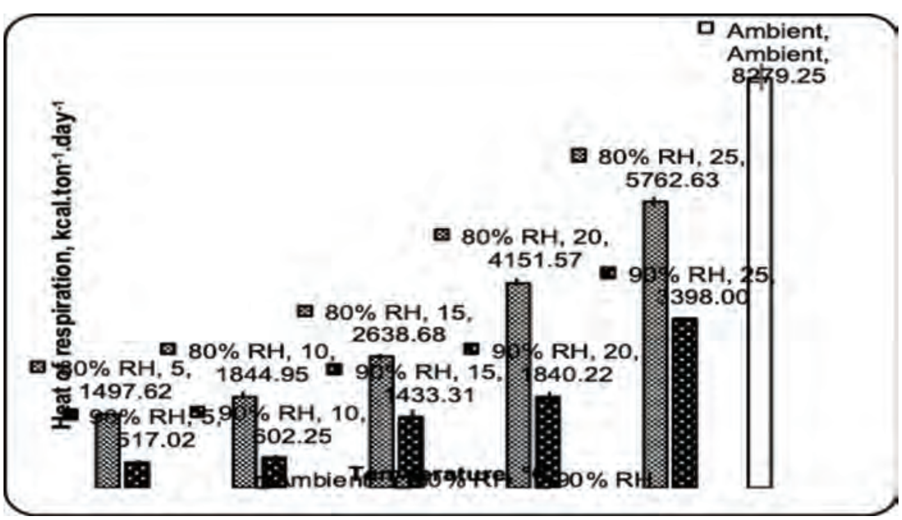

Fig. 4. Heat of respiration of green chilli after one hour storage

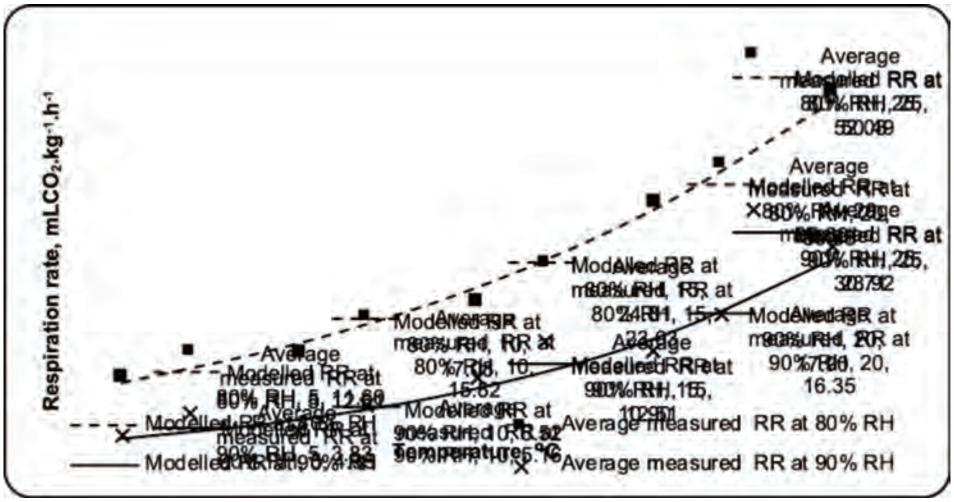

Fig. 5. Modelled and average measured respiration rate as a function of temperature for green chilli at 80 and 90% RH

day^{-1} and 517.02 to 3398.00 kcal.ton^{-1}.day^{-1}at 5 to 25°C, and 80 and 90% RH, respectively (Fig. 4). The green chilli stored under ambient condition had significantly ($p \leq 0.05$) higher heat of respiration of 8279.25 kcal. ton^{-1}.day^{-1} which decreased over a period of time. The results obtained are in agreement with the findings of Scholz *et al*. (1963) who reported the heat of respiration of sweet pepper as 888 kcal.ton^{-1}.day^{-1}, 1392 kcal.ton^{-1}.day^{-1} and 2688 kcal.ton^{-1}.day^{-1}at 10, 15 and 20 °C, respectively. The ANOVA test resulted into significant ($p \leq 0.05$) effect for all storage factors (Table 3). During initial storage periods, high respiration contributed to maximum heat generation and subsequently higher heat load to the cooling system. Kadar (2002) reported that above the critical threshold temperature for safe storage of produce, every 10°C increase in temperature accelerates deterioration and the rate of loss in nutritional quality by 2 to 3 fold. These results signify the importance of the cooling the product at a safe storage temperature as quickly as possible after harvest. Over a period of time, heat load decreased due to decrease in the heat of respiration.

Modelling of respiration rate of green chilli

An Arrhenius-based respiration model was applied to predict the respiration rate of the green chilli in the temperature range of 5°C to 25°C at 80 and 90% RH and was found to be able to predict it with reasonable accuracy as shown in Fig. 5. Estimated model parameters viz., pre-exponential factor (A) and average activation energy (Ea) derived from respiration rate of green chilli for the temperature of 5 to 25°C under 80 and 90% RH are 5.91×10^{8} and 7.17×10^{11} mmolCO_2.kg^{-1}.h^{-1}, and 48302.51 and 67289.27 J.mol^{-1}, respectively. For the measured respiration rate of green chilli at 90% RH had significantly higher Ea than 80% RH, indicating that the respiration rates of green chilli are more sensitive to temperature change at 90% RH. The high respiration rate at low storage humidity resulted in low activation energy at low humidity and hence it may lead to rapid deterioration of the green chilli. Previously, Ea values of 32000 J.mol^{-1} for bell pepper and 70000 J.mol^{-1} for green 'Cayenne' chillies has been reported by Chen *et al*. (2000). Similarly, Jansasithorn *et al*. (2010) estimated 56500, 50500 and 82500 J.mol^{-1} activation energy for Habanero, Jalapeno and Paprika chilli cultivars.

The study concluded that under steady state storage condition respiration rate and heat of respiration of green chilli decreased with time. After one hour of storage, minimum respiration rate and heat of respiration, 4.35 mLCO_2.kg^{-1}.h^{-1} and 517.02 kcal.ton^{-1}.day^{-1} were observed for green chilli stored in 90% RH at 5°C, respectively. Increased storage temperature led to an exponential increase in respiration rate and heat of respiration under both storage humidity. However, increased storage humidity decreased respiration rate and heat of respiration of the green chilli. The Arrhenius model predicted the respiration rate of the green chilli cultivar was found to be accurate for the studied storage conditions. Higher activation energy at 90% RH signifies that maintaining low temperature precisely, can assist to maintain the low respiration rate of the stored produce and thereby in extension of its shelf life.

Acknowledgements

We wish to acknowledge the National Agricultural Science Fund, Indian Council of Agricultural Research (ICAR), New Delhi for funding the project.

Authors' contribution

Conceptualization and designing of the research work (RFS, BBP); Execution of field/lab experiments and data collection (BBP); Analysis of data and interpretation (BBP); Preparation of manuscript (BBP).

LITERATURE CITED

Anonymous 2023. https://agriexchange.apeda.gov.in/India%20Production/India_Productions.aspx?cat=Vegetables&hscode=1076. Accessed on: 23 April, 2023

Azlin R N, Razali M, Zaipun M and Habsah M 2014. Effect of different preconditioning treatments for shelf-life extension of chilli (*Capsicum annuum* L.). *JTrop Agri Food Sci* **42**(2): 135-42.

Chaturani G, Wilson S, Perera S and Hettiarachchi M 2004. Postharvest ripening and respiration of chilli (*Capsicum annum* Var. MI-2). *Proc second acad sessions*, pp. 218-22.

Chen X, Hertog M L and Banks N H 2000. The effect of temperature on gas relations in MA packages for capsicums (*Capsicum annuum* L., *cv.* Tasty): an integrated approach. *Postharvest Biol Technol* **20**(1):71-80.

Chitravathi K, Chauhan O P and Raju P S 2015. Influence of modified atmosphere packaging on shelf-life of green chillies (*Capsicum annuum* L.). *Food Packag Shelf Life* **4**:1-9.

Hameed R, Malik A U, Khan A S, Imran M, Umar M and Riaz R 2013. Evaluating the effect of different storage conditions on quality of green chillies (*Capsicum annuum* L.). *Trop Agric Res* **24**(4): 391-99.

Ul Hasan M, Ullah Malik A, Anwar R, Sattar Khan A, Haider M W, Riaz R, Ali S, Ur Rehman R N and Ziaf K 2021. Postharvest Aloe vera gel coating application maintains the quality of harvested green chilies during cold storage. *JFood Biochem***45**(4): e13682.

Jansasithorn R, East A R, Hewett E W, Mawson A and Heyes J A 2010. Temperature dependency of respiration rates of three chilli cultivars.*Proc IntPostharvest Symp*. pp. 1821-26. Jha S N, Vishwakarma R K, Ahmad T, Rai A and Dixit A K 2015. Report on assessment of quantative harvest and post-harvest losses of major crops and commodities in India. ICAR-All India Coordinated Research Project on Post-Harvest Technology, ICAR-CIPHET, P.O.-PAU, Ludhiana-141004.

Kadar A A 2002. Pre and postharvest factors affecting fresh produce quality, nutritional value, and implications for human health. *Proc Int Cong Food Prod Quality Life*.pp. 109-119.Sassari, Italy.

Mahajan P V, Caleb O J, Singh Z, Watkins C B and Geyer M 2014. Postharvest treatments of fresh produce. *ProcTransac Royal Soc A*, Theme issue: Intelligent Food Logistics, 372(2017), 20130309.

Mann G 1954. The control of relative humidity in cold stores. I. The loss of water from perishable produce during storage. *Institute of Refrigeration (London) Proceedings* **50**: 177-91.

Maskey B, Bhattarai R, Bhattarai G and Shrestha N K 2021. Post-harvest quality of fresh akabare chili (*Capsicum chinese*) as affected by hydrocooling, package modification and storage temperature. *Int J Food Properties* **24**(1): 163-73.

Patel B B, Roy F S, Saiyad M J S and Joshi D C 2016. Respiration behaviour and heat of respiration of mango (*cv.* Langdo) under different storage conditions. *Int J Agri, Environ Biotechnol* **9**:855-59.

Patel B B, Sutar R F and Khanbarad S C 2015. Extension of shelf life of pre-cooled tomato fruit under refrigerated transport condition storage. *JProgress Agri* **6**:1-8.

Raza S A, Khan A S, Malik A U, Amin M, Asad H U and Razzaq K 2013. Respiration rate, physico-chemical fruit quality and consumer acceptability for Fajri mango under different storage temperatures. *Pak J Agric Sci* **50**(4):585–90.

Saxena A, Raghuwanshi R, Gupta V K and Singh H B 2016. Chilli anthracnose: the epidemiology and management. *Frontiers in Microbiol* **7**:1527.

Scholz E W, Johnson H B and Buford W R 1963. Heat evolution rates of some Texas-grown fruits and vegetables. *Rio Grande Valley Hortic Soc J* **17**:170.

Uchino T, Nei D, Hu W and Sorour H 2004. Development of a mathematical model for dependence of respiration rate of fresh produce on temperature and time. *Postharvest Biol technol* **34**(3): 285-93.

Wilkinson B G 1970. Physiological disorders of fruits after harvest. In *Biochemistry of Fruits and their Products,* Hulme A C (ed.). pp. 537-54. Academic Press, London.