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RESEARCH ARTICLE

Effect of different packaging methods and storage conditions on postharvest quality and shelf-life of Manila Tamarind (*Pithecellobium dulce* (Roxb.) Benth.) var. PKM2

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Abstract

Manila tamarind (*Pithecellobium dulce* (Roxb.) Benth.), is a dry land fruit crop that belongs to the Fabaceae family commonly known Camacchile or Jungle jilebi. *Pithecellobium dulce* (Roxb.) has the potential to become productive under harsh climatic and edaphic conditions of dry land areas but its pods have a shorter shelf life. The most important objective was to use proper packaging methods to reduce moisture loss, slow down physiological and biochemical changes and prevent spoilage. The study evaluated 8 packaging methods, including different combinations of CFB (Corrugated Fiberboard) lined with 100-gauge polythene film with 0 %, 5 % and 10 % vents, CFB with 0 %, 5 % and 10 % vents, vacuum packing and a control, under cold storage (13-15 °C) and ambient conditions (26 ± 2 °C). On the 15th day of cold storage conditions, vacuum packing showed minimum physiological loss of weight (19.82 %), titratable acidity (0.68 %), ascorbic acid (77.20) and total sugar (8.36 %). Maximum total soluble solids (15.32 ˚Brix), Anthocyanin (22.72 mg 100 g^{-1} m), shelf life (15 days) followed by CFB with 10 % vent. On the 12th day of ambient storage condition, vacuum packing recorded minimum physiological loss of weight (16.42 %), titratable acidity (0.42 %), ascorbic acid (76.13) and total sugar (8.53 %). Maximum total soluble solids (14.93 ˚Brix), Anthocyanin (21.83 mg 100 g^{-1} m) and shelf life (11.5 days) followed by CFB with 10 % vent. In this study, the overall results indicated that both vacuum packaging and CFB with 10 % vent at cold storage had synergistic effect in manila tamarind fruit pods, not only in extending the shelf life but also maintained the physiological and biochemical attributes of manila tamarind.

Keywords

cold storage; Corrugated fibre board (CFB) packaging; Manila Tamarind; shelf life; vacuum packaging

Introduction

Manila tamarind is one of the major underutilized fruit crops which may be an important fruit for the future due to its high medicinal value, high production per unit area and suitable for wasteland cultivation. Being the second most populous country in the world (1), India holds responsibility of feeding its 1.3 billion people. However, with increasing population pressure and improving standards of living, human survivorship has become one of the most serious challenges for mankind. There is a potential threat of food and nutritional scarcity due to the apathetic exploitation of resources, leading to their depletion. This emerges the need for alternatives, thus exploring the unexplored and underutilised plant species. *Pithecellobium dulce* (Roxb.) Benth. Belongs to the family Fabaceae, native to Mexico, South America and Central America. It is common in India, Malaysia and Thailand. Often planted for living fence or thorny hedge, eventually nearly impenetrable, camachile furnishes food, forage and firewood, while fixing a little nitrogen. In India it is mostly found in states of Tamil Nadu, Andhra Pradesh, Rajasthan, West Bengal and Delhi. The tree bears coiled fruits from end of the April till June. The fruit is a pod having sweet and slightly astringent white and red arils depending upon the tree covering black seeds. The fruit pulp is taken orally to stop blood flow in case of haemoptysis, seeds when grounds are used to cleanse ulcers and also numerous studies have been performed on anti-oxidant, anti-inflammatory, anti-diabetic and anti-cancerous properties (2).

Inadequate postharvest management accounts for 30 to 40 % loss of manila tamarind pods, which are highly perishable in nature. Pods can be stored for 2-3 days under normal conditions. Postharvest management such as packaging and storage technologies are crucial for extending shelf life and retention of nutrients. Fruit pods can be stored at low temperature to slowdown the ripening process. Packaging is also crucial in reducing the risk of pathogens being transported by fresh produce (3). The main objective was to keep the product well-packaged and stored to reduce moisture loss, slow down physical and chemical changes and prevent damage like bruising or spoilage during transport.

Materials and Methods

Collection of Manila Tamarind Fruits

The present experiment was conducted at Department of postharvest technology, Horticultural College and Research Institute, Periyakulam during the month of February to May 2024. Manila tamarind fruits were collected from 5-year-old orchard at Theni, Tamil Nadu, India. The fruits were greenish-brown to red-pinkish, indehiscent Pods. The pods were rather thin, 10-15 cm long and 1-2 cm wide. The spirally twisted fruits with clear constrictions, pale yellow pods and red attractive arils were found in clusters of 2-3. The Pods hold 10 seeds, with the fruit arils displaying a reddish colour. The seeds are flat, black and shiny. There are 48 kg of fruits are taken for this experiment.

Methodology

Manila tamarind harvested at optimum maturity the skin of fruits turns yellow and seeds turn black

⇩

Harvested fruits were collected in perforated plastic trays

⇩

Within an hour after harvesting, fruits kept in a pre-cooling room at 15 °C to remove the field heat and keep the fruits as cool

⇩

After the pre- cooling fruits are packed different packaging treatments

⇩

Packed fruits were stored under ambient (26 ± 2 °C) and cold storage (13 ± 1 °C) conditions for further analysis

⇩

During experimentation, manila tamarind quality parameters were assessed once in 3 days

Laboratory research was conducted at Horticultural College and Research Institute, Periyakulam, Theni district, Tamil Nadu, India during March- June 2024 to evaluate the influence of CBF and vacuum packaging on storage of freshly harvested Manila Tamarind var. PKM2. The treatments include packing of Manila Tamarind var. PKM 2 pods in 8 different treatments of CFB lined with 100 gauge polythene film with 0 % vent, CFB lined with 100 gauge polythene film with 5 % vent, CFB lined with 100 gauge polythene film with 10 % vent, CFB with 0 % vent, CFB with 5 % vent, CFB with 10 % vent, vacuum packing and control. The 16 treatment combinations in the experiment were set up in a 2-factor Factorial Completely Randomized Block Design (FCRD) with 3 replications. The particulars of the treatment are provided in Table 1.

To study physiological and biochemical changes during storage of the fruits under cold and ambient, observations of the fruit samples were recorded at 3 days interval.

Physiological loss in weight

The physiological loss in weight of fruits was assessed at 3 days interval and calculated using the formula given below and expressed in % (4).

$$\text{PLW (\%)} = \frac{\text{Initial weight (g) - Final weight (g)}}{\text{Initial weight (g)}} \times 100$$

Total Soluble Solids (TSS)

TSS With the use of digital refractometer, an LED was allowed to pass light through a prism in contact with the fruit sample. An image sensor determines the critical angle at which the light is no longer refracted through the sample and the TSS of the fruits was calculated in terms of a degree brix.

Table 1. Storage conditions and packaging methods Manila Tamarind var. PKM 2.

Storage conditions and packaging methods Manila Tamarind var. PKM 2	
Factor 1 (Storage condition)	**Factor 2 (Packaging methods)**
S_1 – Cold storage (13-15 °C) S_2 - Ambient condition 26 + 2 °C)	P_1 - CFB lined with 100 gauge polythenefilm with 0 % vent P_2 - CFB lined with 100 gauge polythene film with 5 % vent P_3 - CFB lined with 100 gauge polythene film with 10 % vent P_4 - CFB with 0 % vent P_5 - CFB with 5 % vent P_6 - CFB with 10 % vent P_7 - Vacuum packing P_8 - Control

Titratable acidity (%)

Titratable acidity was determined according to the method described (5). 50 g of manila tamarind flakes was homogenized using a blender. An amount of 10 g of blended flakes was mixed with 25 mL of distilled water and titrated against 0.1 N NaOH using Phenolphthalein indicator. Appearance of faint pink colour indicates the end point and the result was expressed as (mg 100 g^{-1}) citric acid equivalent.

$$\text{Titratable acidity (\%)} = \frac{T \times N \times E \times V_1}{V_2 \times W} \times 100$$

Where,

T-titre value, V1=volume made up, N= normality of NaOH, V2= volume of extract taken for estimation, E= equivalent weight of citric acid, W= weight of sample taken for estimation.

Ascorbic acid (mg 100 g^{-1})

Ascorbic acid content was estimated according to method prescribed (6) and formula given below.

$$\text{Amount of ascorbic acid present in 100 g of sample} = \frac{0.5\text{ mg}}{V_1\text{ mL}} \times \frac{V_2}{5\text{ mL}} \times \frac{0.5\text{ mg}}{V_1\text{ mL}} \times 100$$

Total sugars (%)

Total sugars were calculated using the anthrone method. It was computed using the following formula and expressed as a % (7).

$$\text{Total sugars (\%)} = \frac{\text{Sugar value from graph (mg)} \times \text{Total volume of extract (mL)}}{\text{Aliquot taken (mL)} \times \text{Weight of the sample (mg)}} \times 100$$

Anthocyanin

Anthocyanin was extracted from the sample by blending 10 g of sample with 10 mL of ethanolic HCl and transferred to 100 mL volumetric flask. The volume was made up and the solution was stored in refrigerator at 4 °C and then filtered through Whatman No.l filter paper. Optical density of filtrate was recorded at 535 nm (8).

$$\text{Total O.D/100 g} = \frac{\text{O.D X Volume made up}}{\text{Weight of sample}} \times 100$$

$$\text{Total anthocyanin (mg/ l00 g)} = \frac{\text{Total O.D/100 g}}{98.2}$$

Shelf life (days)

The shelf-life of berries in each treatment was determined by recording number of days, where fruit pods retain their appearance and fit for consumption, without any decay. The shelf-life of fruits is expressed in days.

Statistical analysis:

The statistical analysis was performed using AGRES software version SVN-1FN. Factorial Completely Randomized Design (FCRD) was used to understand the main effects of with and without ventilation, storage conditions and their interaction effects for the various parameters observed in the packed manila tamarind fruits. The mean comparisons was made after computing analysis of variance (ANOVA), standard deviation [SE (d)] and least significant differences (LSD) with p = 0.05 level of significance (9).

Results

Physiological loss in weight (% PLW)

During the storage period, the mean physiological loss in weight gradually increased and ranged from 3.69 to 19.82 % (3^{th} day to 15^{th} day). Among the various packaging methods, minimum mean PLW of 2.85 % was recorded in P_7 vacuum packaging) followed by 3.15 % in P_6 whereas, a maximum mean PLW of 4.27 % was noted in P_8 on 3^{rd} day of storage. At the end of the storage period (12^{th} day), P_7 recorded minimum PLW of 14.99 % whereas, a maximum PLW of 15.52 % was recorded in P_8 (control). Among the storage conditions, manila tamarind fruit pods stored at cold storage (S_1) recorded minimum mean values of PLW (3.10 %, 6.58 %, 10.37 % and 14.54 %) whereas, maximum mean values of PLW (4.28 %, 7.50 %, 10.45 % and 16.42 %) was recorded in fruits stored at ambient storage (S_2) on 3^{rd}, 3^{th}, 6^{th}, 9^{th} and 12^{th} day of storage respectively. The interaction between packaging and storage conditions inferred that the minimum PLW (2.21 %, 4.98 %) was observed in P_7S_1 (vacuum packaging at cold storage) followed by (2.59 %, 5.36 %) in P_6S_1 (CFB with 10 % vent at cold storage) on 3^{rd} and 6^{th} day of storage. Whereas, maximum PLW (4.83 %) was observed in P_8S_2 (control at ambient storage) on 3^{rd} day of storage (Table 2).

Table 2. Effect of packaging methods and storage conditions on physiological weight loss (%) of manila tamarind during storage.

Treatments	Storage (days)														
	3 Day			6 Day			9 Day			12 Day			15 Day		
	S_1	S_2	Mean	S_1	S_2	Mea	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
P_1	3.68	4.69	**4.18**	8.53	-	**8.53**	-	-	**-**	-	-	**-**	-	-	**-**
P_2	3.38	4.57	**3.97**	7.28	-	**7.28**	-	-	**-**	-	-	**-**	-	-	**-**
P_3	2.64	3.80	**3.22**	5.97	7.82	**6.89**	10.53	-	**10.53**	-	-	**-**	-	-	**-**
P_4	3.52	4.62	**4.07**	7.81	-	**7.81**	-	-	**-**	-	-	**-**	-	-	**-**
P_5	3.11	4.53	**3.82**	6.14	8.26	**7.20**	11.82	-	**11.82**	-	-	**-**	-	-	**-**
P_6	2.59	3.71	**3.15**	5.36	7.13	**6.24**	9.85	-	**9.85**	15.52	-	**15.52**	-	-	**-**
P_7	2.21	3.50	**2.85**	4.98	6.82	**5.90**	9.31	10.45	**9.88**	13.57	16.42	**14.99**	19.82	-	**19.82**
P_8	3.72	4.83	**4.27**	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
Mean	**3.10**	**4.28**	**3.69**	**6.58**	**7.50**	**7.12**	**10.37**	**10.45**	**10.52**	**14.54**	**16.42**	**15.25**	**19.8**	**-**	**19.82**
Factors	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**
SE (d)	0.062	0.123	0.175	0.082	0.16	0.232	0.08	0.161	0.227	0.081	0.162	0.229	0.099	0.198	0.28
C.D (p=0.05)	0.13**	0.26**	0.21*	0.175**	0.35**	0.49**	0.17**	0.34**	0.48**	0.17**	0.34**	0.48**	0.21**	0.42**	0.59**

(*- significant at 5 % level; **-significant at 1 % level; NS- Non Significant).

Total Soluble Solids (TSS °Brix)

During storage, mean values of TSS increased from 13.55 ºBrix to 14.44 ºBrix on 3rd to 9th day. From 12th to 15th day, TSS decreased from 14.31 ºBrix to 13.51 ºBrix. Among the various packaging methods, minimum increase in TSS (12.45 ºBrix and 12.40 ºBrix) was recorded in P_7 vacuum followed by 12.50 ºBrix, 13.50 ºBrix and 13.79 ºBrix in P_6 (CFB with 10 % vent) whereas, maximum increase in TSS 13.6 ºBrix was noted in P_8 on 3rd day of storage. On ninth day of storage, all the packed fruit pods at ambient storage were decayed, except vacuum packaging and cold stored pods came up to 15 days P_7. At end of the Storage 12th day, TSS started decreasing and it was minimum TSS content (14.2 ºBrix) in P_7 followed by (14.42 ºBrix) in P_6. The fruits pods stored at cold storage (S_1) recorded minimum increase in TSS (12.52 ºBrix to 13.51 ºBrix) from 3rd to 15th day of storage whereas, maximum increase in TSS (14.58 ºBrix to 14.93 ºBrix) was observed in fruits stored at ambient storage (S_2) from 3rd to 12th day of storage. Fruits stored in ambient condition were discarded after 12th days due to decay. The interaction effect on 3rd day but the lower TSS was observed (10.80 ºBrix) in P_7S_1 (vacuum packaging at cold storage) and the higher TSS was recorded in P_8S_2 (control at ambient storage) is 15.70 ºBrix. On 3rd day of storage, all the packed fruits pods at ambient storage were decayed on ninth day, except vacuum packaging fruits pods and cold stored fruits came up to 15 days (P_7 - vacuum packaging). At the end of storage period minimum TSS was observed (13.48 ºBrix) in P_7S_1 (vacuum packaging at cold storage) and the maximum TSS was recorded in P_7S_2 (vacuum packaging at ambient storage) is 14.93 ºBrix on 12th day of storage (Table 3).

Table 3. Effect of packaging methods and storage conditions on total soluble solids (°Brix) of manila tamarind during storage.

Treatments	Storage (days)														
	3 Day			6 Day			9 Day			12 Day			15 Day		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
P_1	12.69	13.64	**13.16**	14.84	-	**14.84**	-	-	**-**	-	-	**-**	-	-	**-**
P_2	13.40	14.67	**14.03**	14.20	-	**14.2**	-	-	**-**	-	-	**-**	-	-	**-**
P_3	11.90	14.70	**13.3**	13.20	15.80	**14.5**	14.78	-	**14.78**	-	-	**-**	-	-	**-**
P_4	13.20	15.30	**14.25**	14.50	-	**14.5**	-	-	**-**	-	-	**-**	-	-	**-**
P_5	12.70	14.80	**13.75**	13.90	15.90	**14.9**	15.08	-	**15.08**	-	-	**-**	-	-	**-**
P_6	11.20	13.80	**12.5**	12.30	14.70	**13.5**	13.79	-	**13.79**	14.42	-	**14.42**	-	-	**-**
P_7	10.80	14.10	**12.45**	11.70	15.10	**13.4**	13.45	14.79	**14.12**	13.48	14.93	**14.20**	13.51	-	**13.51**
P_8	14.32	15.70	**15.01**	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
Mean	**12.52**	**14.58**	**13.55**	**13.52**	**15.37**	**14.26**	**14.27**	**14.79**	**14.44**	**13.95**	**14.93**	**14.31**	**13.51**		**13.51**
Factors	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**
SE (d)	0.221	0.442	0.625	0.172	0.344	0.486	0.111	0.222	0.314	0.079	0.157	0.223	0.068	0.135	0.191
C.D (p=0.05)	0.472**	0.945**	NS	0.367**	0.735**	1.039*	0.237**	0.475**	0.671**	0.168**	0.336**	0.476**	0.144**	0.289**	0.409**

(*- significant at 5 % level; **-significant at 1 % level; NS- Non Significant).

Titratable acidity (%)

The maximum acidity (1.87 %) was recorded in P_7 followed by 1.66 % in P_6, minimum acidity (1.45 %) was noted in P_8 (Control) on 3rd day of storage. On ninth day of storage, all the manila tamarind fruits pods at ambient storage were decayed, except vacuum packaging manila tamarind pods and cold stored fruits came up to 15 days P_7. The mean acidity of 1.01 % was recorded in vacuum packaging (P_7) on ninth day. On the 12th and 15th day of storage, maximum acidity (1.05 % and 0.68 %) was noted in P_7 followed by 3.45 % in P_6 (CFB with 10 % vent), at 12th day of storage. Among the various storage conditions, cold storage (S_1) recorded the higher values of acidity (4.64 %, 4.17 %, 4.08 %, 3.75 % and 3.68 %) on 3rd, 6th, 9th, 12th and 15th day of storage whereas, lower values of acidity (4.46 %, 3.88 % and 3.76 %) were observed in manila tamarind fruits pods stored at ambient storage (S_2) on 3rd, 6th, 9th and 12th day of storage, respectively. Manila tamarind fruit pods stored at ambient storage (S_1) were discarded after 12th days of storage due to decay. On Day 3, there is no significant difference between packaging and storage conditions. The results showed that the acidity was higher (4.91 % and 4.65 %) in P_7S_1 (vacuum packaging at cold storage) Followed by (4.70 % and 4.56 %) in P_6S_1 (CFB with 10 % vent at cold storage) on 3rd and 6th day of storage respectively. whereas, acidity was lower in P_8S_2 (control at ambient storage) with 4.39 % on 3rd day of storage. At the end of 12th day of storage, lowest acidity (3.45 %) was recorded in P_6S_1 (CFB with 10 % vent at cold storage) and highest acidity (4.05 %) was recorded in T_6S_2 (vacuum packaging at cold storage) (Table 4).

Ascorbic acid (mg 100 g^{-1})

The mean value of ascorbic acid content decreased from 83.09 mg 100 g^{-1} on 3rd day to 77.20 mg 100 g^{-1} on 15th day of storage. Results showed that the maximum ascorbic acid content (86.20 mg 100 g^{-1}) was recorded in P_7 which was on par with 85.65 mg 100 g^{-1} in P_6 followed by 85.30 mg 100 g^{-1} in P_3 (CFB lined with 100 gauge polythene film with 10 % vent) whereas, minimum ascorbic acid content (78.58 mg 100 g^{-1}) was noted in P_8 on 3rd day of storage. On ninth day of storage, all the packed fruits pods at ambient storage were decayed, except vacuum packed fruit pods and cold stored fruits came up to 15th days (vacuum packaging). The mean ascorbic acid of 80.32 mg 100 g^{-1} was recorded in vacuum packaging (P_7) on ninth day. At the end of storage period, maximum ascorbic acid content (77.20 mg 100 g^{-1}) was recorded in P_7. Among the various storage conditions, manila tamarind fruit pods stored at cold storage (S_1) recorded maximum ascorbic acid content (84.79 to 77.20 mg 100 g^{-1}) on 3rd to 15th day of storage whereas, minimum ascorbic acid content (81.38 to 76.13 mg 100 g^{-1}) was recorded in fruits stored at ambient storage (S_2) on 3rd to 12th day of storage. Fruits stored at ambient storage were discarded after 12th days of storage due to decay. The interaction between edible coatings and storage conditions inferred that the higher values of ascorbic acid content (88.10 and 85.25 mg 100 g^{-1}) was registered in P_7S_1 (vacuum packaging at cold storage) followed by 87.90 and 82.90 mg 100 g^{-1} in P_6S_1 (CFB with 10% vent at cold storage) on 3rd and 6th day of storage, respectively. Whereas, lower values were noted in P_8S_2 (control at ambient storage) with 77.56 mg 100 g^{-1} on 3rd day of storage (Table 5).

Total Sugar (%)

The mean value of total sugar content starts increased up to ninth day (8.68 to 8.71 %) and then starts decreasing from 12th to 15th day (8.47 to 8.36 %). Results showed that the minimum total sugar content of 8.22 % was recorded in P7 followed by 8.55 % in P_6 whereas, maximum total sugar content of 8.91 % was noted in P_8 on 3rd day of storage. On ninth day of storage, all the packed fruits pods at ambient storage were decayed, except vacuum packaging fruits pods and cold stored fruits came up to 15

Table 4. Effect of packaging methods and storage conditions on titratable acidity (%) of manila tamarind during storage.

Treat-ments	Storage (days)														
	3 Day			6 day			9 day			12 day			15 Day		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
P_1	1.56	1.39	**1.47**	0.88	-	**0.88**	-	-	-	-	-	-	-	-	-
P_2	1.46	1.27	**1.36**	0.92	-	**0.92**	-	-	-	-	-	-	-	-	-
P_3	1.75	1.34	**1.54**	1.13	0.45	**0.79**	0.74	-	**0.74**	-	-	-	-	-	-
P_4	1.59	1.34	**1.46**	1.91	-	**0.91**	-	-	**-**	-	-	-	-	-	-
P_5	1.65	1.56	**1.60**	1.15	0.83	**0.99**	0.13	-	**0.13**	-	-	-	-	-	-
P_6	1.70	1.63	**1.66**	1.56	1.02	**1.29**	1.21	-	**1.21**	0.45	-	**0.45**	-	-	-
P_7	1.91	1.83	**1.87**	1.65	1.24	**1.44**	1.26	0.76	**1.01**	1.05	0.42	**0.73**	0.68	-	**0.68**
P_8	1.52	1.39	**1.45**	-	-	-	-	-	-	-	-	-	-	-	**-**
Mean	**1.64**	**1.46**	**1.55**	**1.17**	**0.88**	**1.03**	**1.08**	**0.76**	**1.02**	**0.75**	**0.42**	**0.59**	**0.68**	**-**	**0.68**
Factors	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**
SE (d)	0.071	0.143	0.202	0.049	0.099	0.14	0.032	0.064	0.09	0.022	0.045	0.063	0.018	0.037	0.052
C.D (p=0.05)	0.15**	0.28**	NS	0.10**	0.21**	0.29**	0.06**	0.13**	0.19**	0.04**	0.09**	0.13**	0.03**	0.07**	0.11**

(*- significant at 5 % level; **-significant at 1 % level; NS- Non Significant).

Table 5. Effect of packaging methods and storage conditions on ascorbic acid (mg 100 g^{-1}) of manila tamarind during storage.

Treatments	Storage (days)														
	3 day			6 day			9 day			12 day			15 day		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
P_1	82.70	80.01	**81.35**	77.21	-	**77.21**	-	-	**-**	-	-	**-**	-	-	**-**
P_2	82.40	79.74	**81.07**	76.27	-	**76.27**	-	-	**-**	-	-	**-**	-	-	**-**
P_3	87.80	82.80	**85.3**	82.93	77.43	**80.18**	78.98	-	**78.98**	-	-	**-**	-	-	**-**
P_4	83.66	81.03	**82.34**	77.61	-	**77.61**	-	-	**-**	-	-	**-**	-	-	**-**
P_5	86.20	82.24	**84.22**	80.97	76.42	**78.69**	77.78	-	**77.78**	-	-	**-**	-	-	**-**
P_6	87.90	83.40	**85.65**	82.90	78.05	**80.47**	79.15	-	**79.15**	77.37	-	**77.37**	-	-	**-**
P_7	88.10	84.30	**86.2**	85.25	82.87	**84.06**	80.32	78.86	**79.59**	79.57	76.13	**77.85**	77.20	-	**77.20**
P_8	79.60	77.56	**78.58**	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
Mean	**84.79**	**81.38**	**83.09**	**80.44**	**78.69**	**79.21**	**79.05**	**78.86**	**78.87**	**78.47**	**76.13**	**77.61**	**77.20**	**-**	**77.20**
Factors	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**
SE (d)	1.312	2.623	3.710	0.966	1.931	2.731	0.683	1.366	1.932	0.453	0.905	1.280	0.386	0.772	1.092
C.D (p=0.05)	2.80**	5.32**	6.13*	2.06**	4.12**	5.84*	1.46**	2.92**	4.13**	0.96**	1.93**	2.73**	0.82**	1.65**	2.334**

(*- significant at 5 % level; **-significant at 1 % level; NS- Non Significant).

days P_7. The mean total sugars of 8.88 % were observed in vacuum packaging (P_7) on ninth day. At the end of storage period, minimum total sugar content of 8.36 % was recorded in P_7. Among the various storage conditions, manila tamarind fruit pods stored at cold storage (S_2) recorded minimum total sugar content (8.20 % to 8.36 %) from 3rd to 15th day of storage whereas, maximum total sugar content (9.16 % to 9.26 %) was observed in fruits stored at ambient storage (S_2) from 3rd to 6th day of storage. Fruits pods stored at ambient storage were discarded after fifteen days of storage due to decay. There is no significant difference between packaging and storage conditions on 3rd day and it was inferred that the lower values of total sugar content (7.92 % and 8.26 %) was registered in P_7S_1 (vacuum packaging at cold storage) followed by 8.06 and 8.45 % in P_6S_1 (CFB with 10 % vent at cold storage) whereas, higher values were noted (9.21 %) in P_7S_2 (control at ambient storage) on 3rd day of storage. During 12th day of storage, minimum total sugar content of 8.46 % was recorded in P_7S_1 (vacuum packaging at cold storage) whereas, maximum total sugar content was recorded in P_6S_1 - CFB with 10 % vent at cold storage with 8.49 % (Table 6).

Table 6. Effect of packaging methods and storage conditions on total sugar (%) of manila tamarind during storage.

Treatments	Storage (days)														
	3 day			6 day			9 day			12 day			15 Day		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
P_1	8.25	9.40	**8.82**	8.79	-	**8.79**	-	-		-	-	-	-	-	-
P_2	8.47	9.50	**8.98**	8.82	-	**8.82**	-	-		-	-	-	-	-	-
P_3	8.06	9.11	**8.58**	8.54	9.30	**8.92**	8.74	-	**8.74**	-	-	-	-	-	-
P_4	8.14	9.35	**8.74**	8.78	-	**8.78**	-	-	**-**	-	-	-	-	-	-
P_5	8.10	9.19	**8.64**	8.85	9.34	**9.09**	8.74	-	**8.74**	-	-	-	-	-	-
P_6	8.06	9.05	**8.55**	8.45	9.27	**8.86**	8.51	-	**8.51**	8.49	-	**8.49**	-	-	-
P_7	7.92	8.52	**8.22**	8.26	9.14	**8.7**	8.85	8.91	**8.88**	8.40	8.53	**8.46**	8.36	-	**8.36**
P_8	8.61	9.21	**8.91**	-	-	-	-	-	-	-	-	-	-	-	-
Mean	**8.20**	**9.16**	**8.68**	**8.64**	**9.26**	**8.85**	**8.71**	**8.91**	**8.71**	**8.44**	**8.53**	**8.47**	**8.36**	**-**	**8.36**
Factors	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**
SE (d)	0.139	0.278	0.394	0.106	0.212	0.299	0.146	0.293	0.414	0.047	0.094	0.133	0.042	0.084	0.118
C.D (p=0.05)	0.29**	0.54**	NS	0.22**	0.45**	0.64***	0.14**	0.29**	0.41**	0.10**	0.20**	0.28**	0.08**	0.17**	0.25**

(*- significant at 5 % level; **-significant at 1 % level; NS- Non Significant).

Anthocyanin (mg 100 g^{-1})

The anthocyanin content of manila tamarind fruit pods was initially increased up to 12th day and decreased at the end of storage period. Results showed that the maximum anthocyanin content (18.23 mg 100 g^{-1}) was recorded in P_7 followed by (18.00 mg 100 g^{-1}) in P_6 whereas, minimum anthocyanin content (15.53 mg 100 g^{-1}) was observed in P_8 on 3rd day of storage. On 9th day of storage, all the packed fruits pods at ambient storage were decayed, except vacuum packaging fruits pods cold stored fruits came up to 15 days P_7. The mean total anthocyanin content of 21.67 mg 100 g^{-1} was recorded in vacuum packaging (P_7) on 9th day. At the end of storage period (12th day), total carotenoid content (23.25 mg 100 g^{-1}) was higher in P_7 followed by 24.43 mg 100 g^{-1} in P_6. Among the various storage conditions, fruits stored at cold storage (S_1) recorded the highest anthocyanin content (17.94 mg 100 g^{-1}) whereas, lowest anthocyanin content (16.71 mg 100 g^{-1}) was observed in fruits stored at ambient storage (S_2) on 3rd day of storage. During 12th day of storage, fruits stored at cold storage (S_1) recorded the anthocyanin content of about 24.55 mg 100 g^{-1} whereas, fruits stored at ambient storage (S_2) recorded the anthocyanin content of (21.83 mg 100 g^{-1}) on 12th day of storage and the fruits were discarded after 12th day of storage due to decay. The interaction between packaging and storage conditions showed that the anthocyanin content was higher (18.91 mg 100 g^{-1}) in P_7S_1 (vacuum packaging at cold storage) followed by (18.76 mg 100 g^{-1}) P_6S_1 (CFB with 10 % vent at cold storage) whereas, lower (15.03 mg 100 g^{-1}) in P_8S_2 (control at ambient storage) on 3rd day of storage. At the end of storage period 12th day, highest anthocyanin content (24.67 mg 100 g^{-1}) was recorded in P_7S_1 (vacuum packaging at cold storage) followed by 24.43 mg 100 g^{-1} in P_6S_1 (CFB with 10 % vent at cold storage) (Table 7).

Shelf life

Among the packaging, maximum shelf life 12.00 days was recorded in P_7 followed by 10.00 days in P_6, 7.5 days in P_3 (CFB lined with 100-gauge polythene film with 10 % vent) and 6.75 days in P_5 (CFB with 5 % vent) whereas, minimum shelf life of 2.75 days was recorded in P_8. Among the storage conditions, cold storage (S_1) extended the shelf life of about 8.06 days whereas, fruits stored at ambient storage (S_2) had the shelf life of about 4.87 days only. The interaction between packaging and storage conditions indicated that the maximum shelf life of 15.00 days was observed in P_7S_1 (vacuum packaging at cold storage) (Fig. 1) followed by 11.5 days in P_6S_1 (CFB with 10 % vent at cold storage), 9.0 days in P_3S_1 (CFB lined with 100 gauge polythene film with 10 % vent at cold storage) and 8.5 days in P_5S_1 (CFB with 5 % vent at cold storage) whereas, minimum shelf life of 2.5 days was observed in P_8S_2 (control at ambient storage) on par with 2.5 days in P_1S_2 (CFB lined with 100 gauge polythene film with 0 % vent at ambient storage) (Table 8).

Microbial count (log CFU g^{1})

One of the important factors in preservation and commercialization of fresh fruits is its shelf life and microbial activity (10). The manila tamarind fruits pods packed with vacuum packaging had shown bacteria, fungi, yeast and mould of 6.97,5.03 and 4.07 log CFU g^{1} (ambient storage) and 1.02, 5.82 and 3.80 log CFU g^{1} (cold storage) whereas, the control fruits had a bacteria, fungi, yeast and mould of 6.97, 9.52 and 5.01 log CFU g^{1} (ambient storage) and 6.62, 9.02 and 4.95 log CFU g^{1} (cold storage) during 15th day of storage respectively (Fig. 2) (Table 9).

Table 7. Effect of packaging methods and storage conditions on anthocyanin (mg 100 g^{-1}) of manila tamarind during storage.

Treatments	Storage (days)														
	3 day			6 day			9 day			12 day			15 day		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
P_1	17.64	16.65	**17.14**	20.18	-	**20.18**	-	-	-	-	-	-	-	-	-
P_2	17.42	16.21	**16.81**	20.21	-	**20.21**	-	-	-	-	-	-	-	-	-
P_3	18.31	17.04	**17.67**	21.56	19.24	**20.40**	21.97	-	**21.97**	-	-	-	-	-	-
P_4	17.87	16.86	**17.36**	20.34	-	**20.34**	-	-	-	-	-	-	-	-	-
P_5	18.64	17.14	**17.89**	21.21	19.58	**20.39**	22.23	-	**22.23**	-	-	-	-	-	-
P_6	18.76	17.24	**18.00**	21.56	19.23	**20.39**	22.74	-	**22.74**	24.43	-	**24.43**	-	-	-
P_7	18.91	17.56	**18.23**	21.67	19.58	**20.62**	22.94	20.40	**21.67**	24.67	21.83	**23.25**	22.72	-	**22.72**
P_8	16.03	15.03	**15.53**	-	-	-	-	-	-	-	-	-	-	-	-
Mean	**17.94**	**16.71**	**17.33**	**20.96**	**19.40**	**20.36**	**22.47**	**20.40**	**22.15**	**24.55**	**21.83**	**23.84**	**22.72**	**-**	**22.72**
Factors	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**
SE (d)	0.272	0.543	0.768	0.293	0.586	0.829	0.2	0.4	0.566	0.174	0.348	0.492	0.114	0.227	0.321
C.D (p=0.05)	0.58**	1.16**	1.67*	0.62**	1.25**	1.77**	0.42**	0.85**	1.21**	0.37**	0.74**	1.05**	0.24**	0.48**	0.68**

(*- significant at 5 % level; **-significant at 1 % level; NS- Non Significant).

Fig. 1. Effect of vacuum packaging under cold storage observed on 3rd, 6th, 9th, 12th and 15th days.

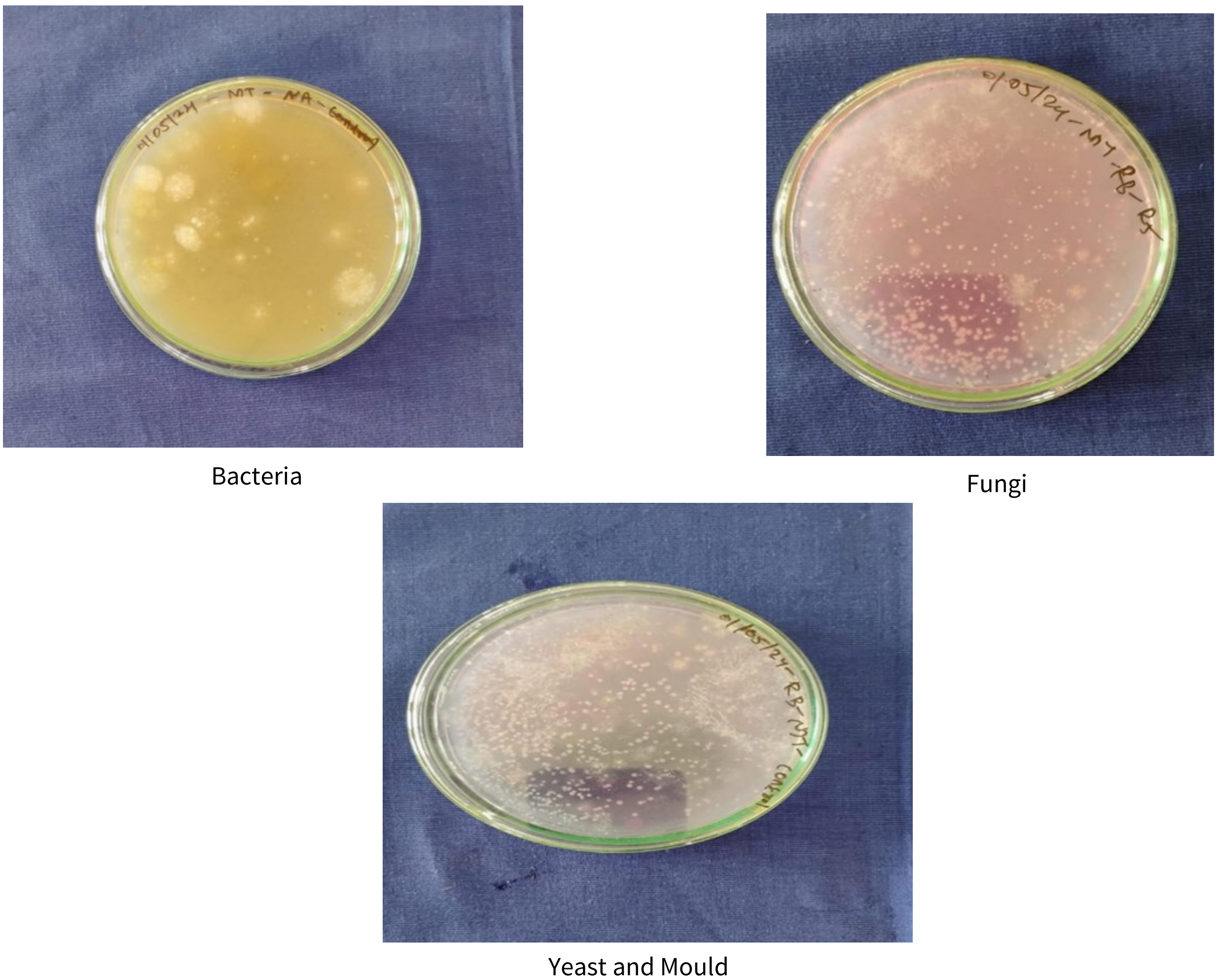

Fig. 2. Effect of packaging methods and storage conditions on microbial count observed in Manilla tamarind.

Table 8. Effect of packaging methods and storage conditions on shelf life (days) of manila tamarind during storage.

Treatments	Shelf life (days)		Mean
	S_1	S_2	
P_1	5.50	2.50	**4.00**
P_2	6.00	3.00	**4.50**
P_3	9.00	6.00	**7.50**
P_4	6.00	2.50	**4.25**
P_5	8.50	5.00	**6.75**
P_6	11.50	8.50	**10.00**
P_7	15.00	11.5	**12.75**
P_8	3.00	2.50	**2.75**
Mean	**8.06**	**4.87**	**6.46**
	SE (d)	**C.D (p=0.05)**	
Storage (S)	0.113	0.243**	
Packaging (P)	0.227	0.485**	
S×P	0.321	0.686*	

(*- significant at 5 % level; **-significant at 1 % level; NS- Non Significant).

Discussion

Physiological loss in weight (% PLW)

Loss of weight on prolonging the storage period mainly was attributed to the loss of moisture caused by evaporation and respiration (11) and may also be due to changes in peel stomatal density as well as texture (12). The PLW of manila tamarind occurs due to the reduction in moisture content. This slower rates of weight loss in vacuum packed fruits can be attributed to the barrier properties for gas diffusion of stomata (13), the organelles that regulate the transpiration process and gas exchange between the fruit and the environment (14). The less weight loss during cold storage was due to maintenance of the maximum moisture content around the surface of fruit along with storage having high humidity and cold storage conditions (15).

Total Soluble Solids (TSS °Brix)

It is well documented that the filmogenic property of ventilated results in an excellent semi-permeable film around the fruit, modifying the internal atmosphere by reducing O_2 and/or elevating CO_2 and suppressing ethylene evolution. A suppressed respiration rate also slows down the synthesis and the use of metabolites, resulting in lower TSS due to the slower hydrolysis of carbohydrates to sugar. The rate of increase in TSS was found to be faster in fruits stored at room temperature as compared to cold stored fruits (4).

Titratable acidity (%)

These results are corroborated with the findings decreased due to the apparent stability observed as an indicator of metabolic stability, because the same serves as a substrate for such reactions as respiration and production of volatiles during ripening(16, 17).

Ascorbic acid (mg 100 g^{-1})

The loss in ascorbic acid content with the progress of the storage period could be attributed to the rapid conversion of L-ascorbic acid into dehydroascorbic acid in the presence of the L-ascorbic acid oxidase enzyme (18). Similarly, higher vitamin C content in ventilated packaging papaya fruit has also been reported previously by strawberry (19) and mango (20).

Total Sugar (%)

Storage condition influenced the effectiveness of treatments on the total sugars content of manila tamarind fruits pods during storage. It was found to be higher in manila tamarind fruits pods stored at ambient temperature on the 9th day of storage, compared to the fruits stored in cold storage. According to a study, it might be due to the fact that high temperature and low relative humidity at room temperature resulted in conversion of starch and other insoluble carbohydrates in soluble sugars (4). The sugars were further utilized for respiration thus showing the lower content of sugars at the later period of storage. The low temperature in cold storage reduces fruit metabolism, particularly respiratory activity, delaying the ripening process and increasing fruit shelf life up to 2 weeks (21).

Anthocyanin (mg 100 g^{-1})

In the present study, anthocyanin content was higher in vacuum packed fruits in cold storage conditions compared to fruits in ambient storage. The vacuum packaging was much more effective than other corrugated fibre board

Table 9. Effect of packaging methods and storage conditions on microbial count (log CFU g^{-1}) of manila tamarind during storage.

Treatments	Storage (at 15th day)								
	Bacteria			Fungi			Yeast and Mould		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
P_1	6.54	6.82	**6.68**	8.71	8.96	**8.83**	4.62	4.68	**4.65**
P_2	5.37	5.48	**5.42**	8.42	8.57	**8.49**	4.32	4.46	**4.39**
P_3	4.62	5.02	**4.82**	7.91	8.09	**8.00**	4.22	4.32	**4.27**
P_4	6.29	6.37	**6.33**	8.62	8.68	**8.65**	4.52	4.61	**4.56**
P_5	5.83	5.91	**5.87**	8.05	8.27	**8.16**	4.30	4.41	**4.35**
P_6	3.42	4.87	**4.14**	6.21	6.92	**6.56**	4.19	4.28	**4.23**
P_7	1.02	1.13	**1.07**	5.82	5.03	**5.42**	3.80	4.07	**3.93**
P_8	6.62	6.97	**6.79**	9.02	9.52	**9.27**	4.95	5.01	**4.98**
Mean	**4.96**	**5.32**	**5.14**	**7.84**	**8.00**	**7.92**	**4.36**	**4.48**	**4.42**
Factors	**S**	**P**	**S×P**	**S**	**P**	**S×P**	**S**	**P**	**S×P**
SE (d)	0.087	0.174	0.245	0.128	0.256	0.363	0.070	0.139	0.197
C.D (p=0.05)	0.186**	0.371**	0.525**	0.247**	0.548**	0.724*	0.138**	0.297**	0.372*

(*- significant at 5 % level; **-significant at 1 % level; NS- Non Significant).

packaging in reducing the anthocyanin losses. Compared with control, the loss of total anthocyanin in vacuum packaging fruits pods occurred more slowly during storage. It's also observed concurrent biosynthesis of anthocyanin in the pulp along with the development of external purple colour (anthocyanin pigments) during ripening of manila tamarind fruit pods and the decline of anthocyanin content in manila tamarind fruit during storage period (22). The decrease in anthocyanin towards the later part of the storage period may be due to the degradation of anthocyanin pigments (23). Changes in anthocyanin profile due to storage temperature regimes during the storage of manila tamarind fruit pods. In general, the development of colour during postharvest storage of fruit might be due to degradation of chlorophyll content in fruit and increase synthesis of anthocyanin pigments (24).

Shelf life

The shelf life of manila tamarind fruit pods is interconnected with broader physiological and biochemical parameters. Each parameter has its impact on fruit quality and storage life. This extension of the storage period was due to the delay in the ripening process caused by respiration, transpiration and antimicrobial properties of vacuum packaging which also delayed the respiration rate during storage. Vacuum packed fruit pods with cold storage helps improve the shelf-life and postharvest quality of bananas (25). Similar results have been reported in papaya (26), jujube (27), fig (28) and pomegranate (29).

Microbial count (log CFU g^{-1})

In the present study, manila tamarind fruit pads packed with vacuum packaging were found to reduce the microbial growth under cold storage condition (Table 9). Compared to with and without ventilated corrugated fibre board packaging with ventilated packaging on the lid had lowered the microbial countering storage. When fruits stored under cold storage reduces the growth of many microorganisms (30). The phytosanitary measures adopted along with postharvest treatment and MAP ensures absences of Coliforms and Salmonella which were toxic to consumers. In addition to this, use of antimicrobials as postharvest treatment makes the fresh fruit produce to tolerate temperature fluctuations during storage (31). It was stated that the minimum microbial count in vacuum packed apple fruits might be due to its inhibitory effect on microbial growth by strengthening the cell wall compared to control which allows spore spreading, resulting in increased microbial contamination; in addition to this vacuum packaging and corrugated fibre board packaging lower the intracellular pH level, this provides a protective barrier against food borne pathogens (32). It was also reported that the main function of vacuum packaging is to maintain cell wall and firmness which also found to inhibit microbial growth in fresh cut produce (33). Inferred that ventilated CFB Packaging pomegranate arils had lower microbial count (bacteria, fungi, yeast and mould count) than control and also stated that modified atmospheric packaging was advantageous in minimizing the bacterial count only (34).

Conclusion

In this study, the overall results indicated that both vacuum packaging and CFB with 10 % vent at cold storage had synergistic effect in manila tamarind fruit pods, not only in extending the shelf life but also maintained the physiological and biochemical attributes of manila tamarind. Since post-harvest lose is a major problem in fruit crops the packaging will be capable of protecting the product from the transport hazards; minimising the physiological and biochemical changes and losses in weight and storage helps in preventing from microbial damage. Considering the long-term needs of eco-systems other alternatives available like corrugated fibre board boxes and vacuum packaging are used. The CFB with 10 % vent is effective than vacuum packaging due to its cost and easy availability in all areas. So, instead of using vacuum packaging, the CFB with 10 % vent is effective packaging method for manila tamarind fruit to extend the shelf-life.

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Authors' contributions

KSA: Writing of original draft and conceptualization. ATSKRR: Revision of draft, inclusion of tables and figures, proof reading. KSAATSKRRCC: Revision, formatting and Supervision. All the authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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Declaration of generative AI and AI-assisted technologies in the writing process

For paraphrasing few sentences, I have used only the Chatgpt AI tool. For data running and analysis, I have used AGRES software version SVN-1FN.

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