Result and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

The objective of this chapter is to examine and assess how various processing methods, including thermal methods like retort processing, and nonthermal methods such as HPP and PL processing, impact the quality attributes of ripe jackfruit. The focus is on understanding how these diverse processing techniques influence the quality characteristics of the ripe jackfruit, providing insights into the effects of both thermal and nonthermal approaches on the final product during and after processing and throughout its storage period. The impact of both thermal and non-thermal processing methods on the quality characteristics of ripe jackfruit is elaborated in the subsequent section through three distinct experiments:

EXPERIMENT I: THERMAL PROCESS STANDARDISATION OF RJB AND RJP UTILIZING RETORT POUCH PROCESSING

4.1 Effects of retort pouch pasteurisation on the quality of RJB and RJP

Retort pouch processing was carried out to ensure the quality and safety of the ripe jackfruit samples. The effect of retort pouch pasteurisation and retort sterilisation at varying process conditions were studied and discussed below.

4.1.1 Physico-chemical properties of unprocessed ripe jackfruit

The collected ripe jackfruit intended for processing underwent a thorough analysis of its physico-chemical properties, and the results of this analysis have been systematically tabulated in Table 4.1. This comprehensive examination involved assessing various physical and chemical attributes of the fruit, providing a detailed understanding of its composition and characteristics before further processing.

Table 4.1 Physico-chemical and microbial properties of fresh ripe jackfruit prior to retort pouch pasteurisation

Sl.No	Parameters		RJB	RJP
1	pH		4.59 ± 0.17	04.50 ± 0.28
2	TSS (ºBrix)		20.00 ± 0.53	20.60 ± 0.94
3	TA (%)		0.63 ± 0.03	0.62 ± 0.02
4	Total sugar (%)		21.33 ± 0.76	22.56 ± 0.98
5	AA content (mg/100 g)		14.43 ± 0.52	10.32 ± 0.27
6	Colour	L*	66.83 ± 2.41	67.95 ± 0.39
		a*	7.86 ± 0.36	08.65 ± 0.23
		b*	49.88 ± 2.29	58.56 ± 0.29
7	DPPH radical scavenging activity (%)		87.34 ± 4.00	84.13 ± 3.01
8	TPC (mg GAE/g)		71.11 ± 2.56	68.53 ± 2.47
9	TFC (mg RE/g)		40.12 ± 1.44	20.33 ± 0.73

Where, RJB: Ripe jackfruit bulb; RJP: Ripe jackfruit pulp; values are expressed in mean ±SD

4.1.2 Effect of Retort pouch pasteurisation of Ripe jackfruit

4.1.2.1 Effect of retort pouch pasteurisation on pH, TSS and TA of RJB and RJP

The retort pouch pasteurisation of RJB and RJP was performed in a retort under varied process conditions aimed at extending their shelf life. It was observed that the pH levels of thermally processed RJB and RJP were raised compared to those of fresh or unprocessed samples of pH 4.59 ± 0.17 and 4.50 ± 0.28, respectively in RJB and RJP. As suggested by Igual *et al.* (2010), this increase in pH could be attributed to the depletion of organic acids during thermal processing, leading to a reduction in the acidic content of the samples.

The pH value varied from 4.49 ± 0.12 to 5.12 ± 0.18 and 4.50 ± 0.21 to 5.18 ± 0.14 respectively for pasteurised RJB and RJP (Table 4.2). The maximum pH value among the pasteurisation treatments was observed at 99˚C for15 min. which is 5.12 ± 0.18 and

5.18 ± 0.14, and the least pH was observed at 85˚C, one min. (4.49 ± 0.12 and 4.50 ± 0.21) respectively for RJB and RJP. From the data analysis, it was found that applied thermal treatments did not statistically affect pH value of the RJB and RJP ($p > 0.05$). The study conducted by Chakraborty *et al.* (2014) suggests that the absence of a significant impact could be attributed to the insufficient severity of both temperature and time conditions to induce the release of H^+ ions from the sample (ie, RJB and RJP) following thermal pasteurisation. The most remarkable result to emerge from the data is that an increase in acid damage can be caused by long heat contacts, rays, alkalis, enzymes, oxidizers, and copper and iron catalysts which amplify the pH value of ripe jackfruit samples (Astuti *et al.*, 2018). For pH value, the coefficient estimates and the corresponding p-values suggest that, among the test variables used in the study, temperature and time were non-significant model terms with p-values of greater than 0.05. This indicates that pH values were not much affected by temperature and time. The p-value of 0.17 and 0.21 respectively for pasteurisation of RJB and pulp implies the lack of fit is not significant relative to the pure error.

A consistent pattern was noted in the TSS values of retort-processed RJB and RJP. The initial TSS of the fresh RJB and RJP measured 20.00 ± 0.53 ˚Brix and 20.60 ± 0.94 ˚Brix, and after undergoing retort processing for pasteurisation, no significant changes ($p > 0.05$) were observed in TSS. Specifically, the TSS value for pasteurized RJB ranged from 19.00 ± 0.69 to 19.90 ± 0.87 ºBrix, while for pulp, it varied between 19.00 ± 0.72 and 22.00 ± 0.76 ˚Brix. Similar findings were documented in the thermally processed mixed formulations of fruit and vegetable pulps by Gonçalves *et al.* (2020). The study showed that the TSS value of RJB was comparable to the control sample. Additionally, a slight elevation was observed in pasteurised pulp, possibly due to the evaporation of water at higher temperatures, which increased the concentration of the pulp.

The initial TA of the control sample was noted as 0.63±0.03% in RJB. Subsequently, following treatment, a reduction in titratable acidity was observed, reaching 0.63±0.02% to 0.22 ± 0.01% after pasteurisation in RJP and 0.62 ± 0.02% to 0.27 ± 0.01% in RJB. From Fig.4.1 it is evident that a substantial reduction in TA was noted at 95℃ /25

min. in RJB and RJP. The statistical analysis indicated a significant ($p < 0.05$) reduction in TA of the RJB and RJP after thermal treatments, likely due to the loss of organic acids following the treatments. Singh *et al.* (2022) suggested that the reduction in acid content observed in pasteurised guava nectar could be attributed to the instantaneous high temperature causing the Maillard reaction. This reaction may have led to the consumption of amino acids and reducing sugars, ultimately resulting in a decrease in TA content in the retort pouch pasteurised products.

The statistical data suggests that the model is significant and the terms (Process temperature/Pasteurisation temperature, ºC) T, (Time, min) Pt, and Pt^2 are significant contributors to explaining the variation in the dependent variable. The model also appears to have a good fit to the data, as indicated by the high R^2 (0.91), Pred R^2 (0.84) and Adj R^2 values (0.85) for RJP. During statistical analysis, the $R^{2,}$ Pred R^2 and Adj R^2 values for RJB were 0.85, 0.69, and 0.75, respectively. The ANOVA for the response surface model is presented in Appendix A3 and A4. The final equation for TA in terms of coded factors likely represents the regression equation derived from the model. It provides a way to predict the dependent variable (TA) based on the values of the independent variables and is given below. The final regression equation for TA in terms of coded factors is given below.

$$TA_{RJB}\ (\%) = 0.35 - 0.078T - 0.097Pt - 0.021TPt + 0.035T^2 + 0.064Pt^2 \quad \ldots (4.1)$$

$$TA_{RJP}\ (\%) = 0.36 - 0.083\ T - 0.11\ Pt - 0.020TPt + 0.028T^2 + 0.061\ Pt^2 \quad \ldots (4.2)$$

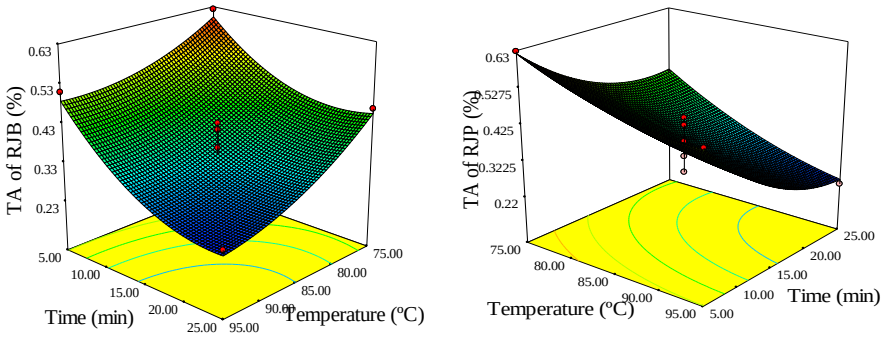
Where, TA_{RJB} and TA_{RJP}: Titrable acidity of RJB and ripe jackfruit pulp respectively

T is the pasteurisation temperature in ºC and Pt is the process time in min.

Table 4.2 Effect of retort pouch pasteurisation on pH, and TSS of ripe jackfruit samples

Pasteurisation temperature (˚C)	Process time (min.)	pH		TSS (˚
		RJB	RJP	RJB
75	5	4.95±0.03	4.78±0.13	19.90±0.87
95	5	4.60±0.21	4.50±0.21	19.90±0.69
75	25	4.86±0.18	4.89±0.03	19.30±0.88
95	25	5.00±0.13	5.10±0.23	19.90±0.72
71	15	4.77±0.06	4.67±0.17	19.50±0.52
99	15	5.12±0.18	5.18±0.14	19.00±0.69
85	1	4.49±0.12	4.50±0.05	19.80±0.71
85	29	5.05±0.22	4.90±0.18	19.50±0.52
85	15	4.90±0.22	5.10±0.13	19.60±0.85
85	15	4.90±0.25	4.82±0.21	19.90±0.91
85	15	4.70±0.17	5.10±0.23	19.50±0.89
85	15	4.80±0.13	4.70±0.22	19.50±0.70
85	15	5.00±0.22	4.90±0.18	19.60±0.52

RJB: Ripe jackfruit bulb; RJP: Ripe jackfruit pulp; Data shown are the mean ± SD of three tr



(a) **(b)**

Fig.4.1 TA of retort pouch pasteurised RJB and RJP

4.1.2.2 Effect of Retort pouch pasteurisation on colour characteristics of ripe jackfruit

The effect of thermal treatment on the colour aspects of ripe jackfruit was studied, and the results were described in terms of CIELAB values. The L* value varied from 65.43 ± 1.59 to 67.63 ± 3.08 in pasteurised RJP and from 64.12 ± 2.70 to 66.63 ± 0.77 for RJB. The study revealed that L* value after pasteurisation non significantly ($p > 0.05$) declines in RJB and RJP. For the RJB, the lightness value slightly decreases after processing, indicating a marginal darkening likely due to natural browning reactions. In contrast, the pulp exhibits more pronounced changes. The lightness value of the RJP decreases slightly, suggesting it has become a bit darker, likely due to browning reactions. Compared with the control sample L* value of 67.95 ± 0.39 and 66.83 ± 2.41 in RJP and RJB the maximum variation was at a higher treatment condition of 99ºC, 15 min. (Fig.4.2 a & b). Aghajanzadeh *et al.* (2018) investigated the impact of thermal processing at 60–90°C for 15 min. on the colour characteristics of key lime juice. Their findings indicated a decline in the L* value with increasing temperatures during the heating process. Demirdoven and Baysal (2014) found that the L*, a*, and b* values of orange juice decreased by 5.5%, 98.1%, and 11.5%, respectively, when heated at 95°C for one min. due to Milliard reaction. The higher L* value or the lightness of the sample was retained at 85˚C one min., the respective L* values at this temperature were 66.63 ± 0.77 and 67.63 ± 3.08 in RJP and RJB.

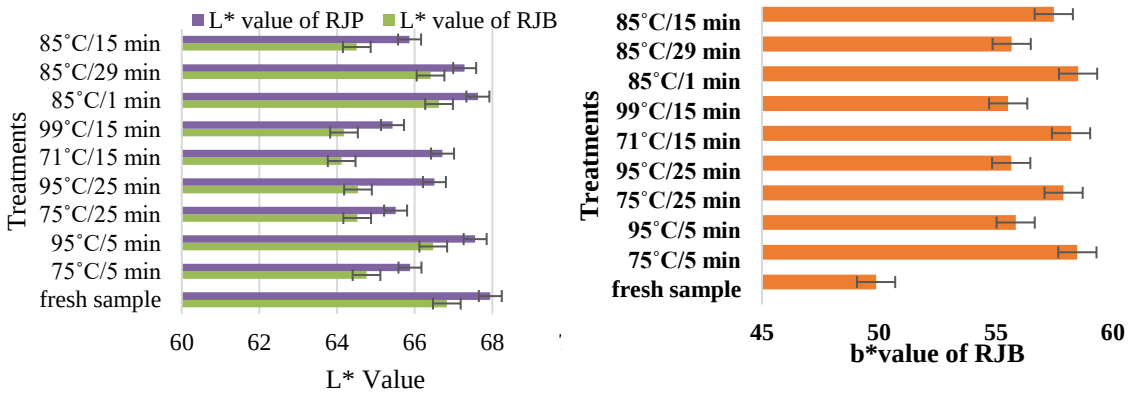
Similarly, the b* value, which represents the yellow to blue index of the sample ranged from 55.53 ± 0.50 to 58.49 ± 1.92 in pasteurised RJP (Fig.4.3a) and from 48.05 ± 1.55 to 49.65 ± 2.33 in RJB (Fig.4.3b). Maximum retention of yellow colour was retrained at a lower temperature and holding time in the pasteurisation process in both jackfruit samples. The a* (red-green) and b* (yellow-blue) values fluctuate slightly, with the b* value showing a minor reduction of 1.72%, suggesting a very slight decrease in yellowness. There was a significant ($p < 0.05$) reducing trend in b* with temperature and time was observed in pasteurised RJP. Compared with the control sample of 58.56 ± 0.29 in RJP there was a maximum reduction of 5.17 % and only 3.22% in pasteurised RJB. Temperature and time had a significant effect on the b* value of both pasteurised RJB and RJP. The study by Rattanathanalerk *et al*, 2005 explained that the decline in b* value at high temperatures may be due to the accelerated carotenoid isomerization, which led to the loss of yellowness. Badina *et al*. (2020) observed that the colour parameters of thermal processed raspberry pulp decreased with treatment time and temperature. Statistical study proved that retort pouch processing had a significant effect on b* value of RJP, and the observed R^2 value = 0.78, Adj R^2 value =0.73 and Pred R^2 value = 0.55. The ANOVA table for the response surface model is presented in Table A5 in Appendix and the regression equation is given below.

$$b^*_{RJP} = 57.06 - 1.08^* T - 0.26^* Pt - 0.067^* T^* Pt - 0.20^* T\,2 + 0.37^* Pt^{2} \quad \ldots (4.3)$$

Where, T: Pasteurisation temperature (˚C), Pt: Process time in min., b^*_{RJB}: b* value of RJP.

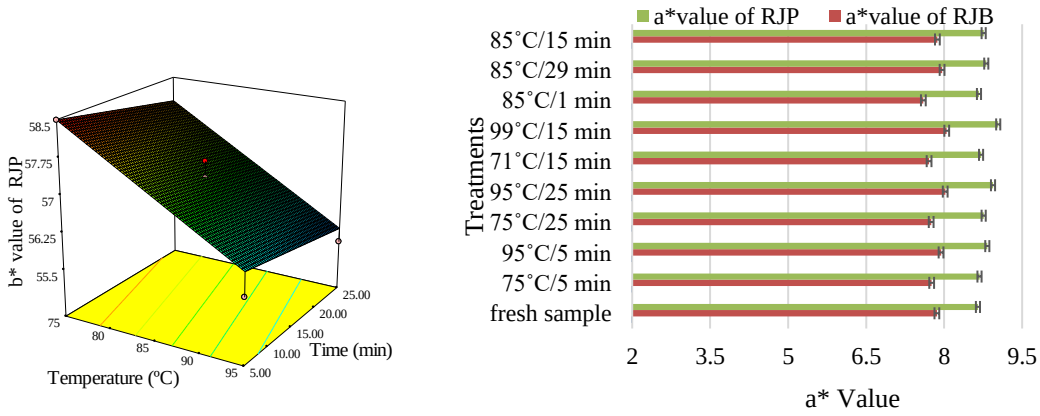
Furthermore, the a* value of RJB and RJP followed an increasing trend after pasteurisation. The control samples reported a* value of 8.65 ± 0.23 and 7.86 ± 0.36 respectively in RJB and RJP. After retort pouch pasteurisation the values varied from 7.14 ± 0.28 to 8.05 ± 0.31 and 8.56 ± 0.25 to 9.04 ± 0.33 respectively in RJB and RJP (Fig.4.2). This increase in a* value indicates the colour shift from yellow to brown in jackfruit samples after retort pouch pasteurisation and was a non significant ($p > 0.05$) variation that was noticeable at higher temperatures and a processing time of 99˚C, 15 min. The major

causes of colour change may be attributed to carotenoid degradation and nonenzymatic browning (Maillard) (Rattanathanalerk *et al.*, 2005).



(a) **(b)**

Fig. 4.2 L* and a* values of retort pouch pasteurised ripe jackfruit samples



(a) **(b)**

Fig. 4.3 b* values of retort pasteurised ripe jackfruit sample

4.1.2.3 Effect of Retort pouch pasteurisation on ΔE, YI and BI of ripe jackfruit

The ΔE value served as a critical index for evaluating colour change. Total colour deviation of pasteurised RJB varied from 0.40 ± 0.08 to 3.17 ± 0.43. As per the reference values, it indicates more colour deviation was at 99˚C, 15 min (Fig.4.4a). Meanwhile, the colour deviation for RJP after retort pouch pasteurisation was 0.46 ± 0.10 to 4.22 ± 0.34

(Fig.4.4b). It had generally been believed that a $\Delta E \geq 3.0$ could indicate a significant visual difference in various situations (Cao *et al.*, 2018). The minor fluctuations in chromatic attributes and the ΔE values imply that the bulb's appearance remains relatively unchanged to the naked eye, which is beneficial for consumer acceptance. The more noticeable changes in ΔE value for the pulp suggest more colour alterations after processing. According to Wu *et al.* (2021), the ΔE value of pasteurised pineapple fruit juice was recorded as 9.88, indicating a notable visual disparity between treated and untreated pineapple fruit juices. The elevation of a* and reduction in b* may be the major causes contributing to the total colour deviation in samples, which can be the effect of Maillard browning (Yi *et al.*, 2017). Similarly, Yuan *et al.* (2022) observed a significantly higher ΔE in pomegranate juice processed at 110℃ for 8.6 seconds compared to thermal retort pouch pasteurisation at 85℃ for 30 seconds. Statistical analysis revealed that process parameters have a significant effect on ΔE of RJB with R^2 value of 0.857(Appendix A6) and non-significant effect on RJP. The regression equation for the suggested quadratic model of ΔE of RJB in terms of the coded equation is given below, and the 3D surface plot showing the effect of independent variables is depicted in Fig.4.4

$$\Delta E_{RJB} = 2.57 - 1.509E\text{-}003\ T + 0.32Pt + 0.21TPt - 0.26T^2 - 0.83Pt^2 \quad \ldots (4.4)$$

Where, T: Pasteurisation temperature (ºC), Pt: Process time in min., ΔE_{RJB}: Total colour deviation of RJB

The YI values obtained for the processed RJB ranged from 103.69 ± 4.64 to 110.39± 5.19, while those for the RJP varied from 118.09 ± 4.93 to 127.54 ± 4.65 (Table 4.3). Notably, the YI values were higher for both the bulb and pulp when pasteurised at 75°C for 5 min., indicating lower colour deterioration compared to other retort pouch pasteurisation conditions. Slight increases in the BI and YI indicate minor browning and yellowing, which could impact the perceived quality and appeal of the pulp. The data suggests that lower retort pouch pasteurisation temperatures result in reduced colour deterioration, as evidenced by the higher YI values observed at 71°C and 75°C for pulp (Fig 4.5b). This phenomenon aligns with the principles of thermal degradation, wherein higher

temperatures accelerate colour changes due to enzymatic and non-enzymatic reactions (Wu *et al.*, 2021).

The BI values for the processed RJB ranged from 93.92 ± 1.05 to 98.08 ± 3.66 (Table 4.3), while those for the pulp varied from 103.16 ± 2.41 to 109.74 ± 2.92 (Fig 4.5a). The lower BI values were observed at 95°C for 25 min. and 95°C for 5 min. may be due to the reduction in b* value suggest that enzymatic browning reactions were active under elevated thermal conditions. This finding aligns with previous research indicating that higher temperatures accelerate enzymatic browning, while shorter processing times minimize the exposure of phenolic compounds to thermal degradation (Badina *et al.*, 2020). The BI value of lettuce juice increased from 33.59 ± 3.01 in the control to 40.94 ± 7.67 during thermal retort pouch pasteurisation (Zhang *et al.*, 2024). Lower temperatures and shorter processing times were found to be effective in reducing enzymatic browning, offering valuable insights for the development of high-quality jackfruit products. According to Badina *et al.* (2020), the BI of thermally processed raspberry pulp was influenced by the increase in process temperature, a* and chroma (C*). The statistical study suggest that the BI values were non-significant for RJB and significant for RJP respectively, meaning that the independent variables in the models had no significant effect on the BI value of RJB. Statistical analysis demonstrated the significant effect ($p < 0.05$) of process temperature and time on BI of RJP and the regression equation for BI of RJP ($R^2 = 0.53$) in terms of coded factors is given in below.

$$BI_{RJP} = 106.75 - 172T - 0.089Pt \quad \ldots(4.5)$$

Where, T: Pasteurisation temperature (ºC), Pt: Process time in min., BI_{RJPB}: Browning index of RJP

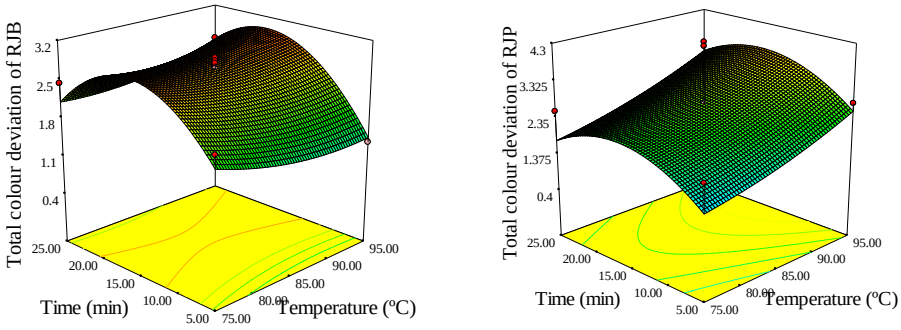


Fig. 4.4 ΔE values of retort pouch pasteurised ripe jackfruit sample

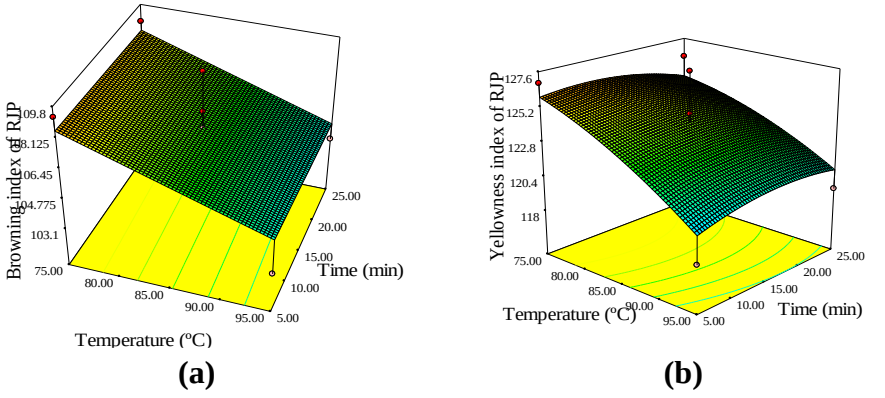


Fig. 4.5 BI and YI of retort pouch pasteurised ripe jackfruit sample respectively

4.1.2.4 Effect of Retort pouch pasteurisation on AA of ripe jackfruit

The initial mean concentration of AA in the RJB and RJP was 14.43 ± 0.52 mg/100 g and 10.32 ± 0.27 mg/100 g, respectively. The retort pouch pasteurisation process significantly influenced the AA content, resulting in a range of 11.03 ± 0.51 to 14.32 ± 0.62 mg/100 g for the RJB (Fig 4.6a) and 6.84 ± 0.18 to 10.28 ± 0.60 mg/100 g for the RJP (Fig 4.6b). The outcomes from thermal treatments revealed a negative impact on AA levels, with an observed increase in both temperature and processing time. The findings indicated that AA exhibited greater susceptibility to thermal instability compared to other assessed quality components. Processing RJP and RJB at 99°C for 15 minutes resulted in a

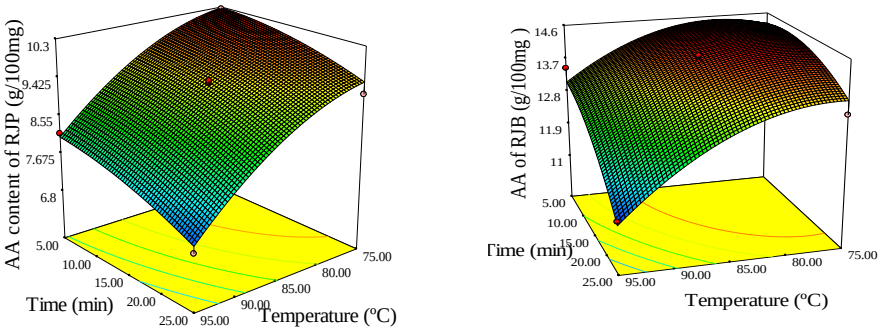
significant reduction in AA content, with RJP showing a 33.72% decrease and RJB a 23.56% decrease. Greater retention of 14.32 ± 0.62 mg/100 g and 10.28 ± 0.60 mg/100 g AA were reported in RJB and RJP ie., complete retention was noted at 71°C for 15 min. compared to the control value. Sinchaipanit *et al.* (2015) documented a decrease in AA content by 26% in guava juice subjected to retort pouch pasteurisation at 85˚C for 1 min. The instability of AA during thermal processing may be the reason for reduction of AA in pasteurised ripe jackfruit samples. Wu *et al.* (2021) reported that high temperatures intensified the loss of AA in the thermally processed pineapple juice.

Statistical analysis demonstrated the significant effect ($p < 0.05$) of process temperature and time on AA content of ripe jackfruit samples. The F values of 29.91 and 49.11 for RJB and RJP respectively indicated the model significance, and the Pred R^2 was in reasonable agreement with the Adj R^2 of the models. The R^2 values for RJP was 0.97 and for RJB it was 0.95 (Table A8 and A9). The regression equation for AA content of ripe jackfruit samples is given below

$$AA_{RJB} = 14.05 - 0.94^{*} T - 0.68^{*} Pt - 0.33^{*} T^{*} Pt - 0.68^{*} T^2 - 0.36^{*} Pt^2 \quad \text{... (4.6)}$$

$$AA_{RJP} = 9.33 - 1.16^{*} T - 0.44^{*} Pt - 0.052^{*} T^{*} Pt - 0.43^{*} T^2 - 0.16^{*} Pt^2 \quad \text{... (4.7)}$$

Where, AA_{RJB}: ascorbic acid of RJB, AA_{RJP} : ascorbic acid of RJP, T: Pasteurisation temperature (˚C) and Pt: Process time in min.



(a) **(b)**

Fig 4.6 AA content of retort pouch pasteurised ripe jackfruit samples

Table 4.3 Effect of Retort pouch pasteurisation on BI and YI of ripe jackfruit samples

Process temperature (˚C)	Process time (min.)	RJB	
		BI	YI
75	5	97.27±4.58	109.10±4.86
95	5	94.53±4.90	104.35±3.76
75	25	97.04±5.05	108.76±2.82
95	25	96.68±3.94	107.93±1.23
71	15	98.08±2.92	110.39±3.88
99	15	96.28±4.80	107.17±2.82
85	1	95.59±3.58	106.45±4.64
85	29	94.79±4.86	105.06±4.86
85	15	95.88±3.91	106.63±4.80
85	15	95.73±2.68	106.73±3.84
85	15	95.34±3.66	106.06±2.81
85	15	93.92±3.56	103.69±4.51
85	15	97.10±2.41	109.18±3.70

RJB: Ripe jackfruit bulb, BI: Browning index, YI: Yellowness index. Data shown are the mean ± SD of three treatment repetition

.4.1.2.5 Effect of Retort pouch pasteurisation on TPC and TFC of ripe jackfruit

The fresh RJB contained 71.11 ± 2.56 mg GAE/g total phenolic content and 40.12 ± 1.44 mg RE/g flavonoids, while the pulp had 68.53 ± 2.47 mg GAE/g total phenolic content and 20.33 ± 0.73 mg RE/g flavonoids. Retort pouch pasteurisation results in a significant ($p<0.05$) reduction in both TPC and TFC in jackfruit samples. Improved preservation of TPC and TFC was documented at lower temperatures and shorter processing times. The investigation yielded TPC values of 58.96 ± 2.12 mg GAE/g to 70.53 ± 2.54 for RJBs (Fig 4.7 a) and 52.33 ± 2.23 to 65.12 ± 2.34 mg GAE/g for pasteurised RJP samples (Fig 4.6 b). Concurrently, TFC values for pasteurised RJB and RJP ranged from

34.02 ± 1.22 to 40.02 ± 1.44 mg RE/g (Fig 4.7 a) and 15.68 ± 0.56 to 19.20 ± 0.69 mg RE/g (Fig 4.8b), respectively.

A comprehensive reduction of 17.08% and 23.63% in TPC was documented in RJB and RJP samples at 99°C for 15 min. Similarly, TFC in pasteurised samples showed an overall reduction of 15.80% and 20.48% for RJB and RJP, respectively, under the same process conditions. When compared with the reduction in AA content, the decrease in TPC and TFC were marginally lower. In contrast to these results, an elevation in phenolic compounds was documented in quince jam, potentially attributed to the modification and breakdown of cell walls, along with the thermal degradation of complexes with proteins (Baroni *et al.*, 2018). Conversely, a decline in total polyphenol content was noted in fruit drinks based on milk (Cilla *et al.*, 2012), likely resulting from the thermal degradation of compounds outside a protective matrix. In statistical analysis, it was reported that the F-values for ANOVA to determine the significance of the overall model were 90.63 and 110.62 for the TPC of RJB and RJP respectively (Table A10 and A11). At the same time, it was 115.50 and 35.10 for the TFC of RJB and RJP respectively (Table A12 and A13). The R^2 values for TPC of RJB and RJP were 0.98,0.98 respectively and 0.98 and 0.96 were for TFC of RJB and RJP respectively. The regression equation for TPC and TFC of pasteurized ripe jackfruit samples as follows;

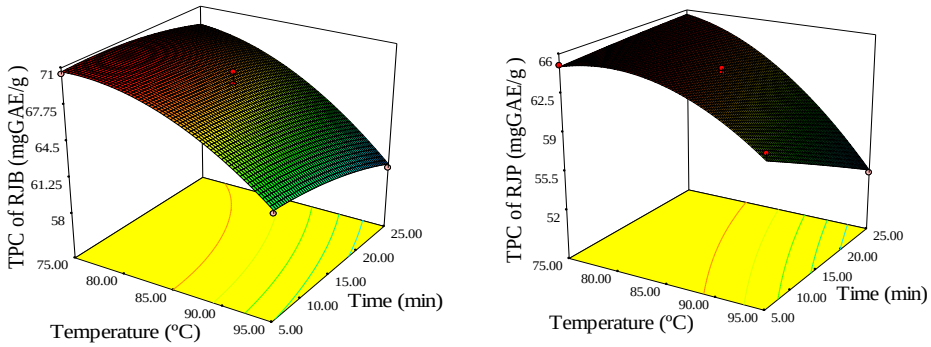
$$TPC_{RJB}\,(\text{mg GAE/g}) = 68.46 - 4.12T - 1.26Pt - 0.57TPt - 2.00T^2 - 0.60Pt^2 \quad \ldots (4.8)$$

$$TPC_{RJP}\,(\text{mg GAE/g}) = 63.40 - 4.27\,T - 1.57\,Pt - 1.90T\,Pt - 2.38\,T^2 - 0.061\,Pt^2 \quad \ldots (4.9)$$

$$TFC_{RJB}\,(\text{mg RE/g}) = 38.21 - 2.05\,T - 1.00\,Pt - 0.36T\,Pt - 0.60\,T^2 - 0.29\,Pt^2 \quad \ldots (4.10)$$

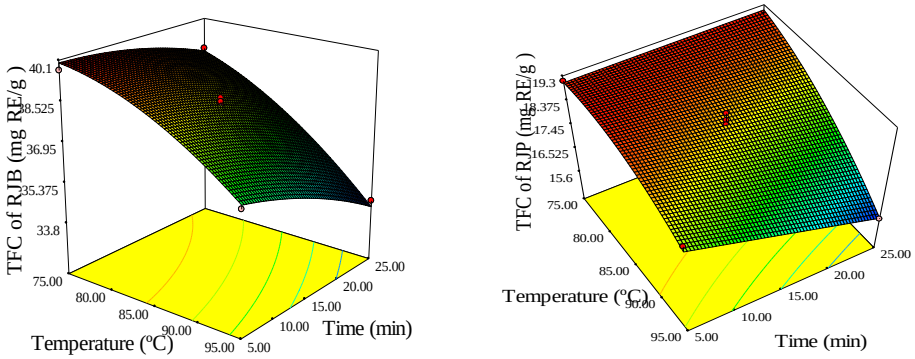
$$TFC_{RJP}\,(\text{mg RE/g}) = 18.43 - 1.14\,T - 0.54Pt - 0.56T\,Pt - 0.47T^2 - 4.00E\text{-}003\,Pt^2 \quad \ldots (4.11)$$

Where, TPC_{RJB}: Total phenolic content of RJB, TFC_{RJB}: Total flavonoid content of RJB, $TPC_{RJP:}$ Total phenolic content of RJP, $TFC_{RJP:}$ Total flavonoid content of RJP, T: Pasteurisation temperature (ºC) and Pt: Process time in min



(a) **(b)**

Fig 4.7 TPC of retort pasteurised ripe jackfruit samples



(a) **(b)**

Fig 4.8. TFC of retort pasteurised ripe jackfruit samples

4.1.2.6 Effect of Retort pouch pasteurisation on Antioxidant activity-DPPH radical scavenging activity of ripe jackfruit

The effect of thermal processing on antioxidant activity in fruits can vary based on factors such as temperature, duration of the processing, and the type of fruit. In the present research, the antioxidant activity was measured by the DPPH (2,2-diphenyl-1-picrylhydrazyl) assay. It varied between 82.33± 2.80 to 86.55 ± 3.12% DPPH radical scavenging activity in RJB (Fig 4.9a) and 79.53 ± 2.10 to 84 ± 3.66% DPPH radical scavenging activity in RJP (Fig 4.9b). Higher retention of DPPH radical scavenging activity was observed at 71˚C and 75˚C respectively at 15 and 5 min. for pasteurized jackfruit RJB and RJP. Maximum loss was 5.73% and 5.46% accordingly in RJB and pulp. Temperature and process time had a significant ($p<0.05$) effect on antioxidant activity. It has been

reported that high temperatures and extended processing times in thermal treatments can reduce antioxidant activity by degrading heat-sensitive antioxidants, affecting their ability to neutralise free radicals. Additionally, the Maillard reaction, triggered at elevated temperatures between amino acids and reducing sugars, can produce compounds with antioxidant properties, which may also contribute to a reduction in overall antioxidant activity. According to Miller and Silva (2012), the decline in antioxidant capacity observed in black mulberry juice at 90°C/30 s was primarily attributed to the loss of total anthocyanins and vitamin C. Similarly, in apple, banana, orange, and strawberry smoothies, a comprehensive reduction in total antioxidant capacity, total phenols, anthocyanins, and color was noted at 70°C/10 min, with the complete inactivation of PPO reported. In the realm of statistical analysis, it was proposed that the F-values in the ANOVA, aimed at assessing the significance of the overall model, reached 11.49 and 17.93 (Table A14 and A15) for the DPPH radical scavenging activity of RJB and RJP, respectively. Equation 4.12 to 4.13 gives the regression equation in coded form. The R^2 value of the RJB and RJP were 0.89 and 0.92 respectively (Table A16 and A17).

$$DPPH_{RJB}\ (\%) = 83.34-1.32T-0.78\ Pt-0.27\ T\ Pt+0.55T^2+0.81\ Pt^2 \quad \ldots. (4.12)$$

$$DPPH_{RJP}\ (\%) = 83.21-1.44T-0.58\ Pt-0.33T\ Pt-0.75T^2-0.14\ Pt^2 \quad \ldots. (4.13)$$

Where, $DPPH_{RJB}$: DPPH radical scavenging activity of RJB, $DPPH_{RJP:}$ DPPH radical scavenging activity of RJP, T: Pasteurisation temperature (˚C) and Pt: Process time in min.

4.1.2.7 Effect of Retort pouch pasteurisation on total sugar of ripe jackfruit

The impact of thermal processing on the total sugar content of fruits can vary based on several factors, including the type of fruit, processing conditions, and the duration of heat exposure. Total sugar content in freshly prepared RJB and RJP was 21.33 ± 0.76% and 22.56 ± 0.98%. After retort pouch pasteurisation, it varied from 15.42 ± 0.53 to 20.22 ± 0.92% in RJB (Fig. 4.10a) and 15.31±0.40 to 22.45 ± 0.80% in RJP (Fig 4.10b). Temperature and process time had a significant effect ($p < 0.05$) on the total sugar content of RJB and RJP. Total sugar content decreased with an increase in temperature and process

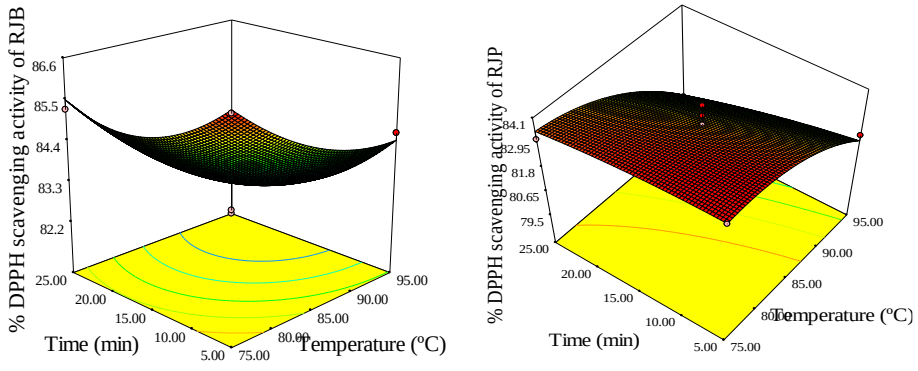
time and maximum reduction was found at 99˚C/15 min. A total of 27.70% and 32.13% reduction was reported as the maximum at this process condition. Extreme heat can lead to the degradation of certain sugar components, potentially resulting in a reduction in total sugar content. Maillard reaction products, formed at elevated temperatures between amino acids and reducing sugars, may contribute to the flavour profile and affect sugar content indirectly. Prolonged or intense heat exposure may lead to the leaching of sugars into the surrounding liquid or syrup, affecting the overall sugar content of the fruit. High temperatures can lead to the caramelization of sugars, contributing to changes in color and flavour. Yikmis *et al.* (2023) noted comparable findings in thermally pasteurized black grape juice, wherein a notable reduction in fructose and glucose levels was evident compared to the untreated control juice, with statistical significance ($p < 0.05$).

The F values of the models were determined as 76.72 and 64.28, respectively for RJB and RJP (Table A16 and A17), and this shows that the developed polynomial model is significant. The coefficient of determination, adjusted R^2 and R^2 values were above 96% which showed that the models were suitable for the experimental results. The significance of the quadratic polynomial model elucidated the impact of temperature, processing time, and the combined effect of temperature and temperature on the total sugar content of jackfruit samples, denoted by a notable coefficient ($p < 0.05$). The regression equation proposed for total sugar is given below

$$\text{Total sugar of RJB (\%)} = 19.02-1.74\ T-0.34Pt-0.37T\ Pt\ -0.64\ T^2-0.089*Pt^2 \quad \ldots (4.14)$$

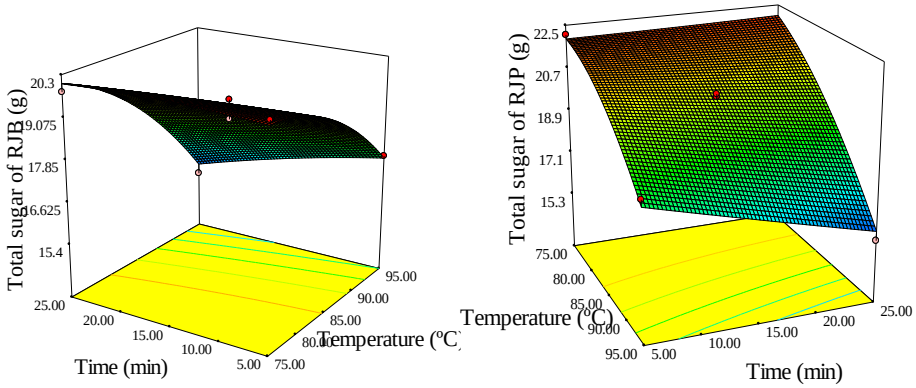
$$\text{Total sugar of RJP (\%)} = 20.24-2.46T\ -0.58\ Pt\ -0.63T\ Pt\ -0.74T^2+.021\ Pt^2 \quad \ldots (4.15)$$

Where, T: Pasteurisation temperature (˚C) and Pt: Process time in min.



(a) **(b)**

Fig.4.9 Effect of Retort pouch pasteurisation on DPPH radical scavenging activity



(a) **(b)**

Fig.4.10 Effect of Retort pouch pasteurisation on total sugar of ripe jackfruit

1.2.8 Effect of Retort pouch pasteurisation on textural property of RJB

The firmness of RJB after retort pouch pasteurisation was evaluated at different temperatures and times. The firmness values ranged from 45.85 ± 0.25 to 54.16 ± 0.54 N, with a control value of 55.46 ± 0.36 N. The highest firmness value was observed at 71°C for 15 min. (54.16 ± 0.54 N), while the lowest value was observed at 99.14°C for 15 min. (45.85 ± 0.25 N). The percentage loss in firmness compared to the control ranged from 2.2% to 17.3%. Generally, as the retort pouch pasteurisation temperature increased, the

firmness of the RJB decreased. However, the time of retort pouch pasteurisation also played a role in the textural properties. At a lower temperature of 71°C, the firmness increased as the time increased from 15 min. to 25 min. (Fig 4.11) However, at higher temperatures (95°C and 99°C), the firmness decreased with increasing time. This suggests that the textural properties of the RJB were affected by a complex interaction between the temperature and time of retort pouch pasteurisation. Overall, the results indicated that the retort pouch pasteurisation process significantly ($p<0.05$) affected the firmness of the RJBs, leading to a reduction in their textural quality. The highest temperature and longest duration led to the greatest loss in texture.

This aligns with the findings of Babu and Sudheer (2020) who observed that texture profile parameters decline as both the duration and temperature of thermal treatment increase for tender jackfruit. The reduction in firmness during thermal processing is mainly due to the degradation of cell wall structures.

The analysis of variance (ANOVA) for the response surface quadratic model reveals that the model is highly significant, with an F-value of 75.55 and a p-value of < 0.0001 (Table A18). This indicates that there is only a 0.01% chance that such a large model F-value could occur due to random noise, which suggests a very strong fit of the model to the data. The R^2 value of 0.981 indicated that the model explained 98.10% of the variation in the data and Eq 4.16 gives the regression equation.

$$\text{Firmness of RJB (N)} = 52.04 - 3.02T - 0.62Pt - 0.30T\,Pt - 1.22T^2 - 0.17Pt^2 \quad \ldots (4.16)$$

Where, T: Pasteurisation temperature (˚C) and Pt: Process time in min.

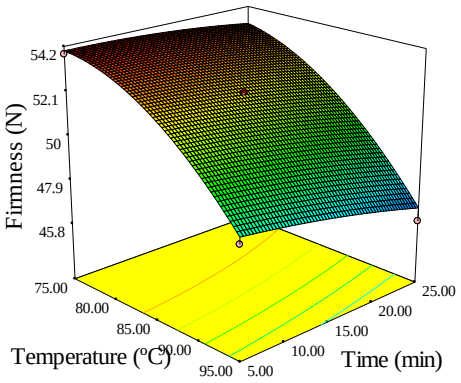


Fig.4.11 Textural property of retort pouch pasteurised RJB

4.1.2.9 Effect of Retort pouch pasteurisation on the rheological properties of RJP

The rheological behaviour of RJP was significantly influenced by variations in pasteurisation temperature and processing time during retort pouch pasteurisation. Dynamic viscosity, a critical parameter in determining the flow properties of fruit pulp, exhibited a general decreasing trend with increasing temperature and holding time, indicating the shear-thinning and non-Newtonian nature of the pulp. The control sample (unprocessed RJP) exhibited an initial viscosity of 60.50 Pa·s, which was reduced to a range of 34.25 ± 0.23 to 61.21 ± 0.02 Pa·s following retort pouch pasteurisation (Fig 4.12). This decline in viscosity highlights the effect of thermal degradation on the pulp's structural integrity.

As the pasteurisation temperature increased, a progressive decline in viscosity was observed across different treatment conditions. At 75°C for 5 min, the viscosity was recorded at 61.21 ± 0.02 Pa·s, whereas a substantial reduction to 36.42 ± 0.02 Pa·s occurred when the temperature was raised to 95°C for the same duration. A similar decreasing pattern was evident at extended processing times, with viscosity dropping from 38.75 ± 0.12 Pa·s at 75°C for 25 min to 35.62 ± 0.02 Pa·s at 95°C for 25 min. This decline can be attributed to the thermal degradation of pectin and polysaccharides, which are primarily responsible for the structural integrity and viscosity of fruit pulps. Previous studies have demonstrated that heat-induced depolymerisation of pectic substances leads to reduced intermolecular interactions, thereby lowering viscosity (Vidigal *et al.*, 2023).

Holding time during retort pouch pasteurisation also played a crucial role in viscosity modification. At a moderate temperature of 85°C, a significant variation in viscosity was observed depending on the duration of treatment. The viscosity of RJP at 85°C for 1 min was 60.24 ± 0.52 Pa·s, whereas an extended pasteurisation time of 29 min resulted in a viscosity of 35.58 ± 0.33 Pa·s, highlighting the substantial impact of prolonged heat exposure.

Remarkably, at 85°C for 15 min, viscosity values varied across different experimental replicates, ranging between 37.25 ± 0.02 Pa·s and 45.12 ± 0.12 Pa·s. This variation may be attributed to differences in pulp composition, moisture redistribution, and localized structural degradation during heat treatment. The breakdown of soluble and insoluble fiber fractions, along with the thermal modification of cell wall polymers, could contribute to this fluctuation. The observed trend aligns with previous reports where extended thermal exposure led to loss of water-binding capacity of hydrocolloids, further reducing viscosity (Vidigal *et al*., 2023).

The variation of viscosity with shear rate illustrated in Fig. 4.13 further confirms the non- newtonian behaviour of RJP. As shear rate increased from 0 to 400 s^{-1}, viscosity decreased consistently across all treatment conditions. The control sample and thermally processed samples exhibited a rapid decline in viscosity at lower shear rates, stabilising at higher shear rates. This trend aligns with shear-thinning behaviour, where intermolecular interactions weaken under shear stress, facilitating flow. Cunha *et al*. (2020) confirmed the shear-thinning behaviour of açai berry pulp across different temperatures, and the reduction in viscosity with increased shear rates. The absence of shear-thickening at any shear rate further supports the suitability of RJP for industrial processing.

Statistical analysis confirmed significant effects of temperature (T) and time (Pt) on viscosity, with p-values of 0.0011 and 0.0005, respectively and R^2 value was 0.92 (Table A19). The model had an F-value of 17.29 (p = 0.0008), confirming statistical significance. The interaction term (T Pt) was not significant (p = 0.0145) but contributed to the model. The lack of fit (p = 0.0066) suggests some unexplained variation, though the residual error

was small, indicating a good model fit. Eq. 4.17 gives the regression equation of dynamic viscosity.

$$\text{Dynamic viscosity (Pa.s)} = 38.91-6.35T-7.27Pt+5.42TPt+1.19T^2+3.97Pt^2 \quad \ldots (4.17)$$

Where, T: Pasteurisation temperature (˚C) and Pt: Process time in min

Overall, thermal treatment rendered the pulp more fluid-like, characteristic of non-Newtonian, shear-thinning materials. No shear-thickening behaviour was observed under any treatment condition, confirming enhanced processability and flow behaviour in industrial applications.

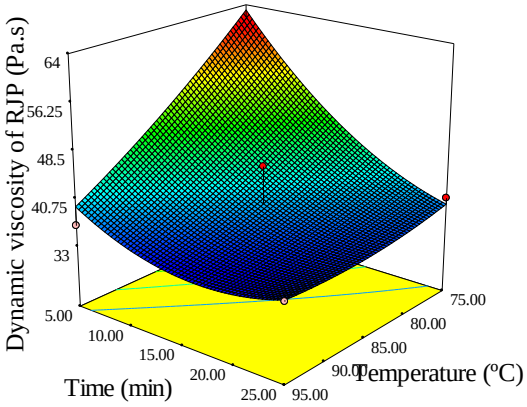


Fig.4.12 Dynamic viscosity of retort pouch pasteurised RJP

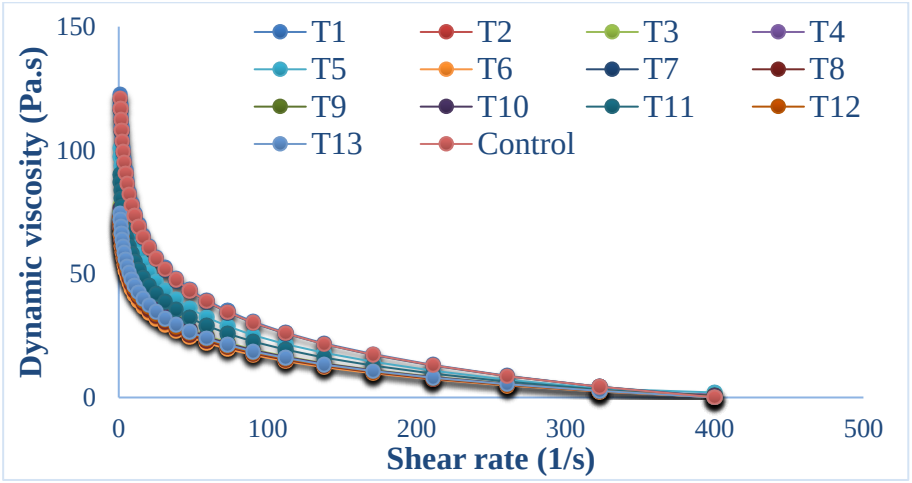


Fig.4.13 Viscosity vs Shear relation for retort pouch pasteurised RJP

4.1.2.10 Microbial analysis of retort pouch pasteurised ripe jackfruit

The initial populations of TAM in pasteurised RJB and RJP were 4.80±1.40 and 5.1±1.32 log CFU/g, respectively. The initial populations of yeast and mold were 4.6±1.55 log CFU/g in RJB and 5.3±1.24 log CFU/g in RJP. The reduction in TAM, yeast and mould in pasteurised ripe jackfruit samples after being subjected to retort pouch pasteurisation at different combinations of process parameters is presented in Fig 4.14 and 4.15. It is clear from Fig 4.13 and 4.14 that the total log reduction in TAM and yeast and mould ranged between 5.42±1.29 to 7.86±1.70 and 5.35±1.82 to 8.85±1.32 log CFU/g, respectively in RJB. These values in RJP varied between 5.50 ± 1.11 to 8.30±4.64 log cfu/g and 6.20±2.36 to 9.30±2.14 log CFU/g, respectively. The data revealed that microbial log reduction was more appreciably noticed over higher temperatures and process time. The highest bacterial log reduction of 7.86±1.70 log CFU/g and 8.30±4.64 log CFU/g in RJB and RJP respectively, was observed in samples treated at 99°C for 15 min. The reduction of yeast and mould was also higher under the same conditions in RJB and RJP. Therefore, the final population of the microbe is approximately zero, indicating an almost complete reduction of the microbes. The extended exposure to high temperatures resulted in the breakdown of microbial membranes and the deactivation of enzymes, thereby allowing for greater reduction in microbial levels at elevated temperatures (Hounhouigan *et al.*, 2020). This finding aligns with the discovery made by researchers who determined that subjecting the pineapple juice to mild heat treatment for 2 min. at 65°C and 8 min. at 63°C resulted in a reduction of yeast population by 6 log units, effectively preserving the nutritional and physicochemical qualities of the juice (Diaz and Aguayo, 2013). Santhirasegaram *et al.* (2013) observed complete inactivation (100%) of aerobic bacteria, coliform, yeast, and mold in thermally treated Chokanan mango juice, with initial microbial counts of 2.74 log CFU/mL, 0.99 log CFU/mL, and 2.42 log CFU/mL, respectively.

The Model F-values of 15.17 and 19.93 in RJB and RJP, respectively, indicate the significant relevance of the model. The response surface plots showing the effect of retort process parameters on microbial log reduction are presented in Fig.4.13 and Fig.4.14. From the figures, it can be observed that there is a decrease in microbial population with an

increase in temperature and time. A second-order regression model was developed relating the log reduction of bacterial and yeast & mold in RJB and RJP with the corresponding combinations of the independent variables in the coded form presented in Equations 4.18 to 4.21. The ANOVA table presented in Appendix A explains the effect of temperature and time on reduction in TAM, yeast and mold in RJB and RJP. The R^2 values for TAM was 0.99 and 0.94 respectively in RJB and RJP (Table A20 and A21). Similarly for yeast and mold the R^2 values noted as 0.91 and 0.93 in RJB and RJP respectively (Table A22 and A23).

Reduction in TAM of RJB (log CFU/g)

$$=6.88+0.87T+0.22Pt+0.11T\,Pt\,-0.14T^2-0.09\,Pt^{\,2} \quad \ldots (4.18)$$

Reduction in Yeast and mould in RJB (log CFU/g)

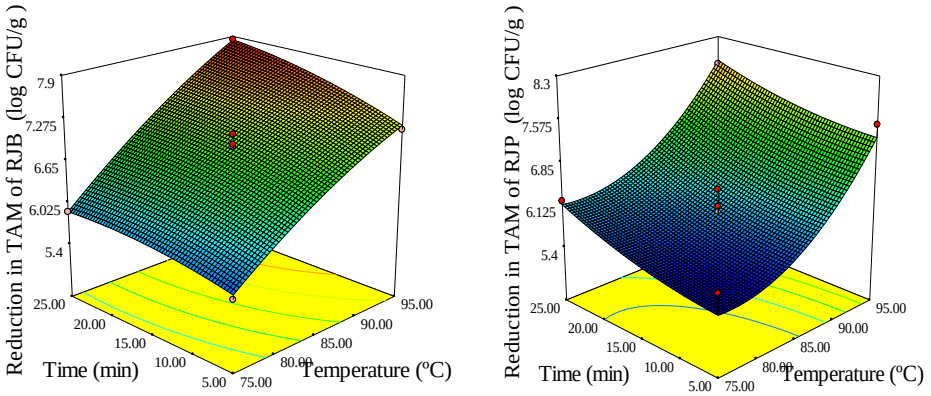
$$=6.33+1.11T\,+0.37\,Pt\,+0.025\,T\,Pt\,+0.42T^2+0.25\,Pt^2 \quad \ldots (4.19)$$

Reduction in TAM of RJP (log CFU/g)

$$=6.04+0.89T\,+0.32Pt\,-0.025TPt\,+0.52T^2+0.12\,Pt^2 \quad \ldots (4.20)$$

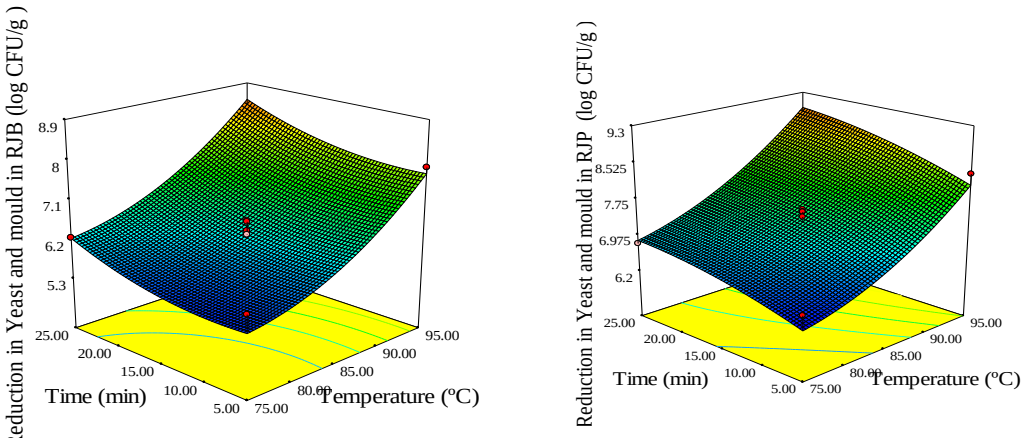
Reduction in Yeast and mould in RJP (log CFU/g)

$$=7.35\,+\,0.98\,T\,+\,0.39\,Pt\,+\,0.060\,TPt\,+\,0.30\,T^2-\,0.13Pt^2 \quad \ldots (4.21)$$



(a) **(b)**

Fig.4.14 Reduction in TAM of retort pasteurised ripe jackfruit samples



(a) **(b)**

Fig.4.15 Reduction in Yeast and mould in retort pasteurised ripe jackfruit sample

4.1.2.11 Sensory evaluation of retort processed ripe jackfruit

The mean sensory scores of the most important organoleptic characteristics that define the acceptance of the sample, such as taste, colour, aroma, texture, and overall acceptance provided by the judges, are presented in Appendix F. The radar chart showing the variation of mean scores is shown in Fig. 4.15 & 4.16. In which the treatments represented as R1:75˚C/5min., R2: 95˚C/5min., R3: 75˚C/25min., R4: 95˚C/25min., R5: 71˚C/15min R6: 99˚C/15min R7: 85˚C/1min R8: 85˚C/29min R9: 85˚C/15min.

It is revealed from the Fig 4.16 and 4.17 that ripe jackfruit samples after retort pouch pasteurisation processing showed the best results in terms of colour, taste, appearance, and overall acceptability and were close to that of the control. Treatments under elevated temperature and time scored comparatively less may be due to the reduction in colour and softness texture due to over-cooking. The major causes of colour change may be attributed to carotenoid degradation and nonenzymatic browning (Maillard) (Rattanathanalerk *et al*., 2005). During the sensory evaluation, it was found that the aroma of all the RJP samples did not stand out or differ notably from the control sample. However, the color of the RJP samples was found to be significant compared to the control. The overall acceptability of the R1 sample (i.e., 75°C for 5 min.) in RJB was high. In the case of RJP the temperature and process time variations had only minor effects on overall acceptability. This suggests that the R1 condition, characterized by 75°C for 5 min., was particularly favorable in terms of overall acceptability for RJB and RJP.

The statistical analysis of retort pouch pasteurised RJB and RJP showed no significant differences in sensory attributes across treatments (RJP: $F = 1.215$, $p = 0.427$; RJB: $F = 0.167$, $p = 0.954$). Correlation analysis indicated that Taste ($r = 0.97$), Texture ($r = 0.93$), and Colour ($r = 0.92$) were the key factors influencing Overall Acceptability. The optimized treatments were R1 (75°C, 5 min) and R7 (85°C, 0.86 min) for RJP and the treatment with balanced sensory scores for RJB. These results suggest that mild to moderate

retort conditions best preserve sensory quality, while extreme processing may reduce acceptability of the processed ripe jackfruit.

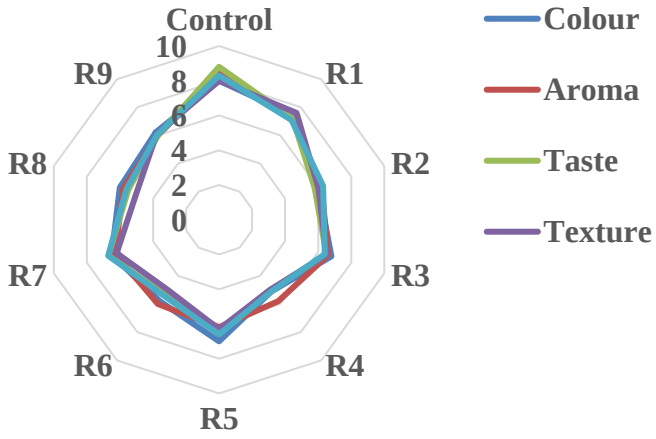


Fig 4.16 Sensory score card of retort pouch pasteurised RJB

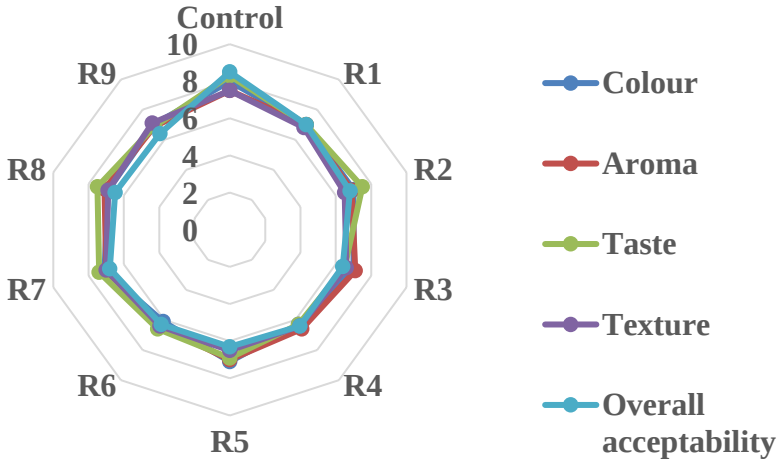


Fig. 4.17 Sensory score card of retort pouch pasteurised RJP

4.1.3 Optimisation of retort pouch processed ripe jackfruit

The optimisation of retort process parameters *viz.*, temperature (75 to 95°C) and time (5 to 25 min) was performed using central composite design (CCD). Treatment combinations with higher desirability values are taken as optimum process conditions. A higher desirability value of 0.987 was obtained for retort pouch pasteurisation of RJB at 79°C temperature 5 min processing time. In the case of RJP, a desirability value of 0.812 is obtained at 80°C temperature 12 min processing time. For RJB, the bioactive compounds were effectively retained, with total aerobic mesophiles (6.06 log CFU/g) and yeast/mold count (5.71 log CFU/g), while firmness was enhanced. Similarly, for RJP, maximum bioactive compound retention and minimal microbial load (5.64 log CFU/g) and yeast/mold count (6.81 log CFU/g) were observed under the optimised conditions.

4.1.4 Cost analysis

The cost estimation and Benefit-Cost Ratio (BCR) for pasteurised RJB and RJP reveal key insights into the profitability of processing these products. It was reported that the cost of producing retort pouch processed RJB amounts to approximately ₹211-/kg, while the current market value for such a product, when sold in syrup, is around ₹699.10 per kilogram. This results in a BCR of 3.3, indicating that for every ₹1 spent on production, a return of ₹3.3 is generated, reflecting a substantial profit margin. For jackfruit pulp, which has a market price of ₹240-/kg, the BCR was calculated to be 1.11, implying a smaller profit margin (Appendix G). This suggests that while both products are profitable, the jackfruit bulb, especially when sold in syrup, provides significantly higher returns compared to the pulp.

4.2 Effect of Retort pouch sterilisation of ripe jackfruit

4.2.1 Physico-chemical properties of unprocessed ripe jackfruit

The collected ripe jackfruit intended for sterilisation underwent a thorough analysis of its physico-chemical properties, and the results of this analysis have been systematically tabulated in Table 4.4. This comprehensive examination involved assessing various physical and chemical attributes of the fruit, providing a detailed understanding of its composition and characteristics before further processing**.**

Table 4.4 Physico-chemical and microbial properties of fresh ripe jackfruit prior to retort pouch sterilisation

Sl.No	Parameters		RJB	RJP
1	pH		5.01 ± 0.23	4.90 ± 0.18
2	TSS (ºBrix)		21.00 ± 0.24	18.50 ± 0.49
3	TA (mg/100 g)		0.58 ± 0.02	0.57 ± 0.02
4	Total sugar (%)		21.33 ± 0.56	22.56 ± 0.81
5	AA (mg/100 g)		13.81 ± 0.48	12.45 ± 0.57
6	Colour	L*	59.32 ± 2.72	66.83 ± 2.56
		a*	0.58 ± 0.03	0.44 ± 0.02
		b*	52.89 ± 2.31	53.56 ± 1.42
7	% DPPH scavenging activity		87.54 ± 2.32	83.29 ± 3.63
8	TPC (mg GAE/g)		71.11 ± 2.56	68.53 ± 2.47
9	TFC (mg RE/g)		40.12 ± 1.44	20.33 ± 0.73

4.2.2 Physico-chemical properties of retort pouch sterilised ripe jackfruit

4.2.2.1 Effect of retort pouch sterilisation on pH, TSS and TA of RJB

The impact of retort pouch sterilisation on the pH, TSS, and TA of RJB and pulp were examined and detailed in Appendix B. The data indicates that the pH ranged from 5±0.23 to 5.6 ± 0.28 in RJB (Fig 4.18a) and 5.06±0.24 to 5.28± 0.19 in RJP samples (Fig 4.18b). This contrasts with the control sample values of 4.9 ± 0.18

and 5.01 ± 0.23 for fresh pulp and bulb, respectively, suggesting a shift towards a more basic pH with increasing temperature and sterilisation time. The analysis reveals a significant rise in pH and a decrease in TA from 0.568% ± 0.03 to 0.152% ± 0.01 and 0.581 ± 0.02 to 0.226% ± 0.01, respectively, in sterilised RJP and RJB (Fig 4.20a &b). Notably, greater variations in pH and TA were observed under higher temperatures and a sterilisation time. This variation is likely due to the reduction in acid content resulting from the loss of organic acids in the jackfruit samples after heat treatment. Similar findings were reported by Velasco-Hernandez *et al*. (2020) for soursop pulp, Santhirasegaram *et al*. (2013) for mango juice.

There was a noticeable increase in TSS in sterilised ripe jackfruit samples, with a range of 18.2± 0.66 ºBrix to 19.5±0.23 ºBrix for RJP (Fig 4.19b) and 21.3±0.54 to 23.4 ± 0.24 °Brix for RJB (Fig 4.19a), compared to 18.5±0.49 ºBrix and 21±0.24 ºBrix in fresh pulp and bulb, respectively. This elevation in TSS, particularly in sterilised RJP, is likely attributed to the higher temperatures causing water evaporation and consequently increasing the pulp's concentration. These results are consistent with the findings of Zhu *et al*. (2022), who observed similar trends in thermally processed mixed formulations of fruit and vegetable pulps, specifically in cloudy apple juice.

The statistical analyses of TSS, pH, and TA for sterilised ripe jackfruit samples (RJB and RJP) reveal significant ($p>0.05$) insights. All three models are highly significant, explaining a substantial portion of the variability in each parameter. TSS was significantly influenced by temperature and an interaction effect was found in RJP, while pH and TA were significantly affected by temperature and time. The lack of fit is not significant relative to the pure error in all three models, indicating a good fit to the data. Overall, the analysis provides a comprehensive understanding of the influence of temperature and time on the quality attributes of sterilised ripe jackfruit bulbs, enabling informed optimization of the sterilisation process. The model regression equation in terms of coded form is given below

$$pH_{RJB} = 5.14+0.16T_S+0.085t_s-0.050T_S\, t_s +0.086\, T_S^2+0.11\, t_s^2 \quad \ldots (4.22)$$

$$pH_{RJP} = 5.24+0.044T_S+0.061t_s +0.015T_S\ ts -0.020\ T_S^2-0.040\ t_s^2 \quad \ldots (4.23)$$

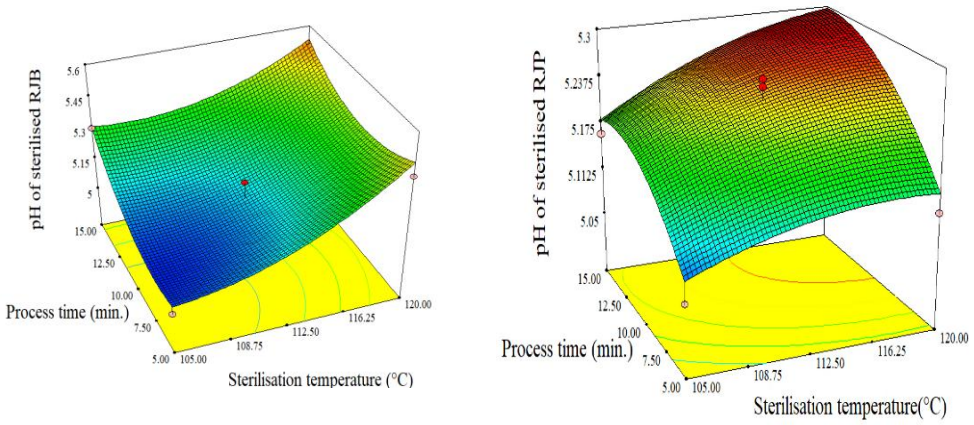
$$TSS_{RJB}\ (^{\circ}Brix) = 22.70+0.66T_S+0.20t_s +0.22T_S\ t_s -0.20T_S^2-0.48\ t_s^2 \quad \ldots (4.24)$$

$$TSS_{RJP}\ (^{\circ}Brix) =18.66+0.33T_S-0.043t_s +0.15\ T_S\ t_s +0.17\ T_S^2-0.030\ t_s^{\ 2} \quad \ldots (4.25)$$

$$TA_{RJB}\ (\%) = 0.47-0.14T_S-0.025\ t_s -0.018T_S\ ts -0.039\ T_S^2+9.763E-003t_s^2 \quad ...(4.26)$$

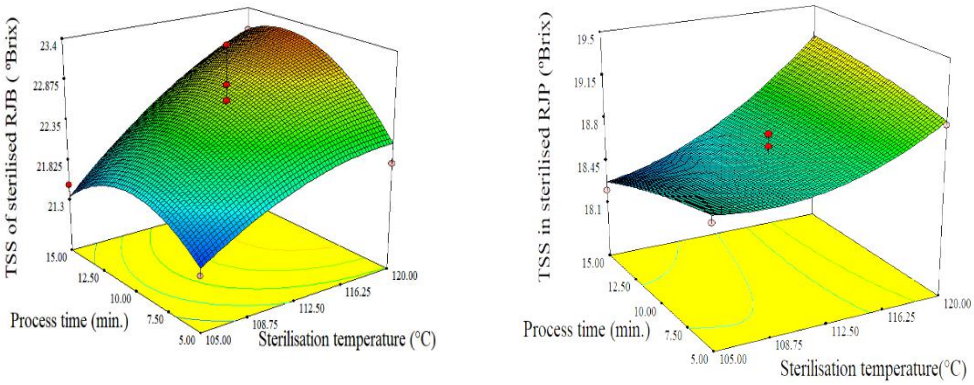
$$TA_{RJP}\ (\%) = 0.43-0.16T_S-0.050t_s +0.010T_S\ t_s -0.029T_S^2-0.049t_s^2 \quad \ldots (4.27)$$

Where, pH_{RJB} and pH_{RJP}: pH of ripe jackfruit bulb and ripe jackfruit pulp, respectively. TSS_{RJB} and TSS_{RJP}: Total soluble solids in ripe jackfruit bulb and ripe jackfruit pulp, respectively. TA_{RJB} and TA_{RJP}: Titrable acidity of ripe jackfruit bulb and ripe jackfruit pulp, respectively. T_s is the sterilisation temperature in ^{o}C and t_s is the process time in min.



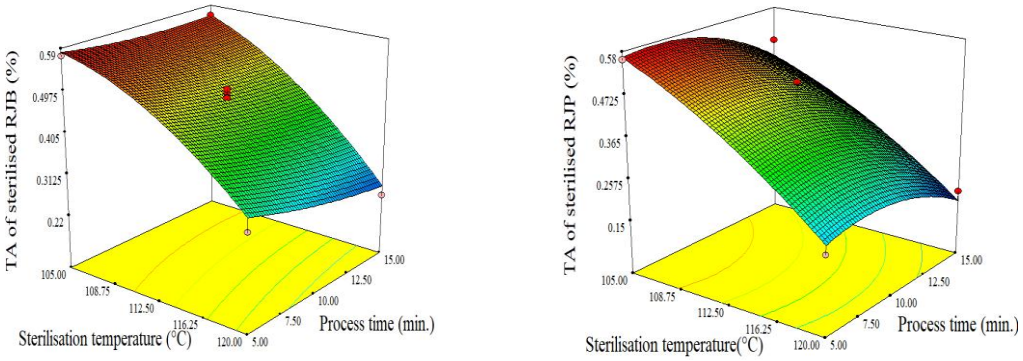
(a) **(b)**

Fig.4.18 pH values of retort pouch sterilised ripe jackfruit samples



(a) **(b)**

Fig. 4.19 TSS in retort pouch sterilised ripe jackfruit samples



(a) **(b)**

Fig.4.20 TA of retort pouch sterilised ripe jackfruit samples

4.2.2.2 Effect of retort pouch sterilisation on colour characteristics of ripe jackfruit

In assessing consumer acceptance and indicating phytochemical changes post-sterilisation colour characteristics play a crucial role in product evaluation. Table 4.4 outlines the colour parameters of fresh ripe jackfruit samples. Following sterilisation the L* value of RJBs increased from 56.15 ± 2.21 to 61.18 ± 2.57 (Fig 4.21a). RJP exhibited a range of L* values from 62.19 ± 1.77 to 66.76 ± 2.85 (Fig 4.21b). At a temperature of 105˚C/5 min and 102˚C for 10 min, L* values exhibited

greater stability, with higher lightness values of 61.18 ± 2.57and 66.76 ± 2.85 were noted in RJB and pulp, respectively. A notable decline in lightness values in ripe jackfruit samples was evident with an increase in both temperature and sterilisation time. Comparable findings were observed by You *et al*. 2018 in sterilised mulberry juice. Conversely, certain studies indicated that sterilisation treatments markedly enhanced the brightness and colour saturation of the juice (Bao *et al*., 2023). Consequently, the determination of whether temperature or time exerts a more substantial influence on juice colour during thermal sterilisation necessitates further investigation.

The ANOVA for the response surface quadratic models for both sterilised RJB and RJP indicates that temperature (T_S) is the most significant factor affecting the L∗ values. For the bulb, temperature shows an F-value of 90.87 with a p-value of < 0.0001 and R^2 value was 0.95, while for the pulp, temperature shows an F-value of 160.30 with a p-value of < 0.0001 and R^2 value was 0.96 (Table B15 and B16). Time (t_s) is also significant for the RJB and RJP with p-values of 0.0091 and 0.011, respectively. Interaction ($T_S t_s$) and quadratic terms (T_S^2 and t_s^2) are not significant for the pulp. Overall, these results suggest that precise control of both temperature and time during the sterilisation process is essential for maintaining the desired quality of the RJB and RJP. The significant terms and the model's good fit indicate that the response surface quadratic model is effective in predicting the L∗ value based on the factors studied. The model regression equation in terms of coded form is given below

$$L^*_{RJB} = 56.65 - 1.57\,T_s - 0.59\,t_s + 0.70\,T_S\,t_s + 0.99\,T_S^2 + 0.21\,t_s^2 \quad \ldots (4.28)$$

$$L^*_{RJP} = 64.46 - 1.62\,T_S - 0.44\,t_s + 0.23\,T_S\,t_s - 0.099\,T_S^2 + 0.039\,t_s^2 \quad \ldots (4.29)$$

Where, L^*_{RJB} and L^*_{RJP}: L* value of ripe jackfruit bulb and ripe jackfruit pulp respectively. Ts is the sterilisation temperature in ^oC and t_s is the process time in min

The sterilisation process resulted in slightly higher a* values and lower b* values, indicating a loss of the fresh yellow colour in ripe jackfruit. Initially, the fresh samples exhibited a* values of 0.58 ± 0.03 and 0.44 ± 0.02 in the RJB and RJP, respectively, with b* values of 52.89 ± 2.31and 53.56 ± 1.42. The a* value varied between 0.61±0.03 to 1.26±0.03 in the RJB (Fig 4.22a) and 0.72 ±0.02to 3.15±0.10 in the RJP (Fig 4.22b) post-sterilisation. Conversely, the variation of b* values was recorded as 47.2±1.70 -53.41±1.92 in the RJB (Fig 4.23a) and 43.3±1.14-53.38±1.92 in the RJP (Fig 4.23b). Comparing the sterilised RJP to the fresh samples, there was a 23.69% loss in b* value, whereas the loss was lower at 10.75% in the bulb. These color changes are attributed to carotenoid degradation and nonenzymatic browning/Maillard reaction degradation of pigments, and the polymerization of phenolic compounds occurring during the sterilisation process (Rattanathanalerk *et al*., 2005).

The significant effect of temperature (T_S) on the a* and b* value implies that the sterilisation temperature is a critical factor in determining the colour of RJB and RJP. The ANOVA for the response surface quadratic models for both sterilised RJB (R^2 value = 0.973) and RJP indicates that temperature (T_S) is the most significant factor affecting the a* and b* values (Table B17 to B19). The R^2 for a* value of RJB is 0.973 and for RJP it is 0.924. The model regression equation in terms of coded form is given below

$$a^*_{RJB} = 0.74 + 0.22T_S + 0.088t_s + 0.057\, T_S\, t_s + 0.10T_S^2 + 0.011\, t_s^2 \quad \ldots (4.30)$$

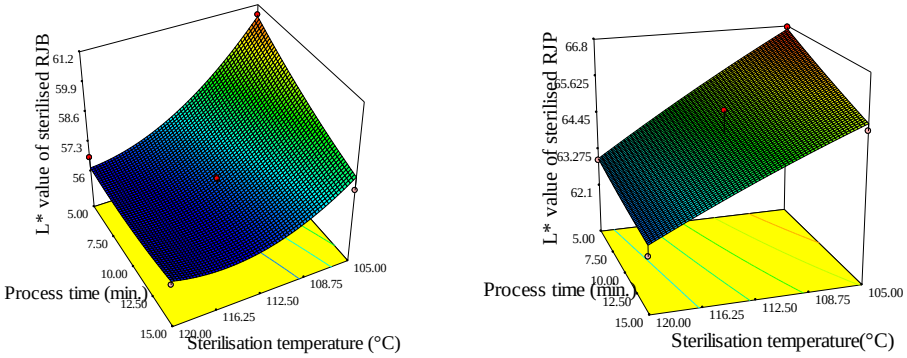
$$a^*_{RJP} = 2.59 + 0.85T_S + 0.41\, t_s - 0.018T_S\, t_s - 0.34T_S^2 - 0.38\, t_s^2 \quad \ldots (4.31)$$

$$b^*_{RJB} = 51.86 - 2.18T_S - 0.65t_s - 0.30\, T_S\, t_s - 0.92\, T_S^2 - 0.43\, t_s^2 \quad \ldots (4.32)$$

$$b^*_{RJP} = 48.46 - 2.53\, T_S - 0.84\, t_s - 1.40\, T_S\, t_s + 0.61\, T_S^2 - 0.48\, t_s^2 \quad \ldots (4.33)$$

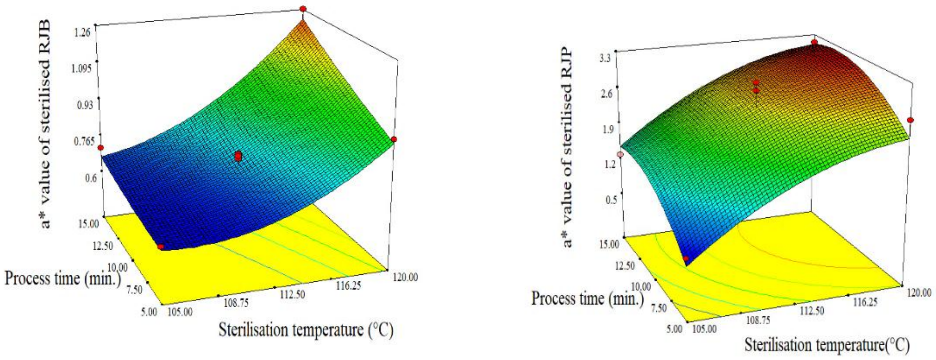
Where, a^*_{RJB} and a^*_{RJP}: a* value of ripe jackfruit bulb and ripe jackfruit pulp respectively. b^*_{RJB} and b^*_{RJP}: a* value of ripe jackfruit bulb and ripe jackfruit pulp respectively

T_s is the sterilisation temperature in ºC and t_s is the process time in min



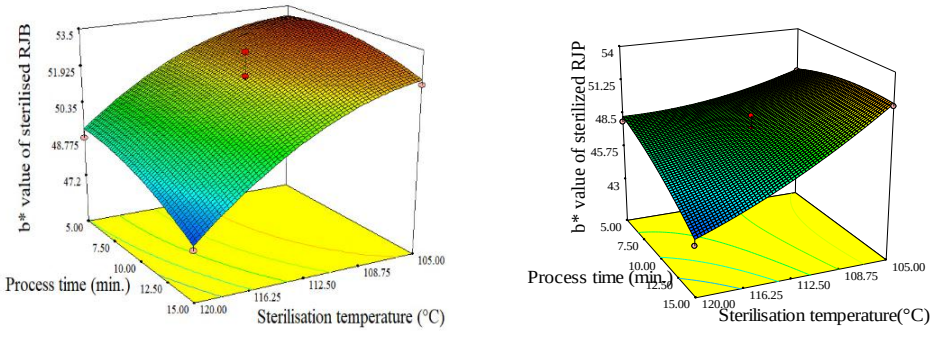
(a) **(b)**

Fig.4.21 L* value of retort pouch sterilised ripe jackfruit samples



(a) **(b)**

Fig.4.22 a* value of retort pouch sterilised ripe jackfruit sample



(a) **(b)**

Fig.4.23 b* value of retort pouch sterilised ripe jackfruit samples

4.2.2.3 Effect of Retort pouch sterilisation on ΔE, YI and BI of ripe jackfruit

The ΔE in ripe jackfruit samples was determined based on the observed L*, a*, and b* values using the standard equation outlined in the materials and methodology. It was found that the sterilised RJB exhibited a ΔE ranging from 1.48 ± 0.08 to 6.52 ± 0.33 (Fig 4.24a), while the pulp showed a ΔE of 6.58 ± 0.13 to 11.18 ± 0.35 (Fig 4.24b). It was observed that all samples experienced noticeable colour deviations following sterilisation with temperature and sterilisation time significantly influencing the ΔE values of both bulb and pulp. Particularly, a higher ΔE value of 6.52 ± 0.33 was noted in sterilised RJB at a higher temperature and sterilisation time of 120˚C for 15 min. Similarly, a ΔE value of 11.18 ± 0.35 was observed in sterilised RJP under at 120˚C for 15 min. The appreciable deviation in color of ripe jackfruit samples is likely attributed to thermal degradation in carotenoids, leading to a decline in b* and an increase in a*.

For the jackfruit bulb, the R^2 value is 0.8093, while for the pulp it is 0.9791, demonstrating that the models explain 80.93% and 97.91% of the variability in the responses, respectively. Temperature (T_S) is the most significant factor for bulb and p-values < 0.0001. Time (t_s) is also significant for RJB.

The data presented in the Fig 4.25 & 4.26 showcases the impact of varying sterilisation conditions on the colour parameters (BI and YI) of retort pouch-sterilised RJP and RJB. Across different temperatures and time intervals, noticeable variations in BI and YI were observed. In RJP, the YI ranged from 99.38 ± 0.24 to 114.48 ± 0.44 (Fig 4.26b), while BI fluctuated between 90.14 ± 1.11 and 97.91 ± 0.99 (Fig. 4.25b), indicating that higher temperatures and prolonged exposure contributed to enhanced browning. Similarly, in RJB, BI values spanned from 101.79 ± 0.21 to 111.50 ± 0.36 (Fig 4.25a), and YI varied between 119.96 ± 0.46 and 133.18 ± 0.74, (Fig 4.26a) suggesting a relatively stable yellowness but a slight increase in browning at higher intensities. This decrease in YI at elevated process conditions may be attributed to a decrease in the b* value due to non-enzymatic reactions and carotenoid

degradation. In RJP, the highest BI (97.91 ± 0.99) and YI (114.48 ± 0.44) were recorded at 102°C for 10 min, while the lowest BI (92.86 ± 0.24) and YI (86.74 ± 1.11) were observed at treatment with the lowest b* values. In RJB, the highest BI (113.71 ± 0.36) was found at 102°C for 10 min, whereas the lowest (95.51 ± 0.21) was recorded at 123°C for 10 min. The highest YI (135.88 ± 0.74) occurred at 102°C for 10 min, and the lowest (110.28 ± 0.46) was at 120°C for 15 min. These results indicate that higher temperatures and prolonged exposure contribute to the degradation of yellow colour, likely due to Maillard reactions and caramelization (Zhang *et al.*, 2024).

The ANOVA results indicated significant quadratic models for all response variables (YI and BI) in both RJB and RJP. Temperature was found to be the most influential factor affecting all responses, and time also showed a significant effect. The interaction between temperature and time was significant for YI and BI of RJP, and for BI in pulp, indicating complex relationships between these factors (Appendix B). While the models showed good fit for all responses, as indicated by high R^2 values (ie., YI_{RJB}= 0.8710, YI_{RJP}= 0.9102, BI_{RJB}= 0.8512 and BI_{RJP}= 0.9081). The regression equation for the ΔE, YI and BI and their contour diagram illustrating the effect of sterilisation on ripe jackfruit samples with varying process conditions are given below

$$\Delta E_{RJB} = 2.76+1.80T_S+0.59t_s+0.31T_S\,t_s+0.78T_S^2+0.075t_s^2 \quad \ldots (4.34)$$

$$\Delta E_{RJP} = 8.01+0.42T_S+0.45t_s+1.40\,T_S\,t_s-0.076T_S^2+0.31\,t_s^2 \quad \ldots (4.35)$$

$$YI_{RJB} = 130.34-2.04\,T_S-0.35\,t_s-2.27\,T_S\,t_s-4.26T_S^2-1.33\,t_s^2 \quad \ldots (4.36)$$

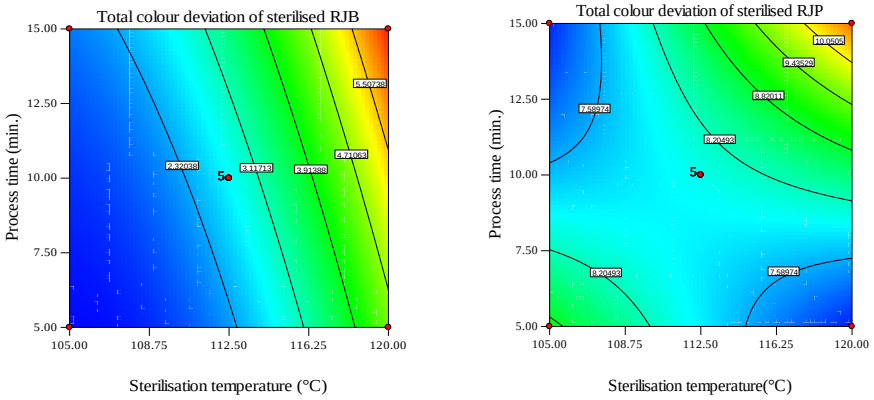
$$YI_{RJP} = 107.40-2.87T_S-1.18\,t_s-3.57\,T_S\,ts+1.45\,T_S^2-1.14t_s^2 \quad \ldots (4.37)$$

$$BI_{RJB} = 109.21-1.37T_S-0.21\,t_s-1.64\,T_S\,t_s-3.14\,T_S^2-1.02\,t_s^2 \quad \ldots (4.38)$$

$$BI_{RJP} = 94.32-1.34T_S-0.47\,t_s-2.05T_S\,t_s+0.77T_S^2-0.80\,t_s^2 \quad \ldots (4.39)$$

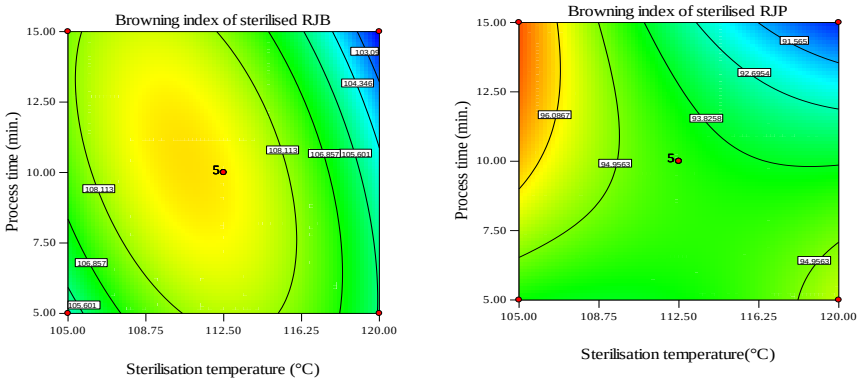
Where, E_{RJB} and E_{RJP}: Total colour deviation of ripe jackfruit bulb and ripe jackfruit pulp respectively. YI_{RJB} and YI_{RJP}: Yellowness index of ripe jackfruit bulb and ripe jackfruit pulp respectively. BI_{RJB} and BI_{RJP}: Browning index of ripe jackfruit bulb and ripe

jackfruit pulp respectively and T_s is the sterilisation temperature in ^oC and t_s is the process time in min



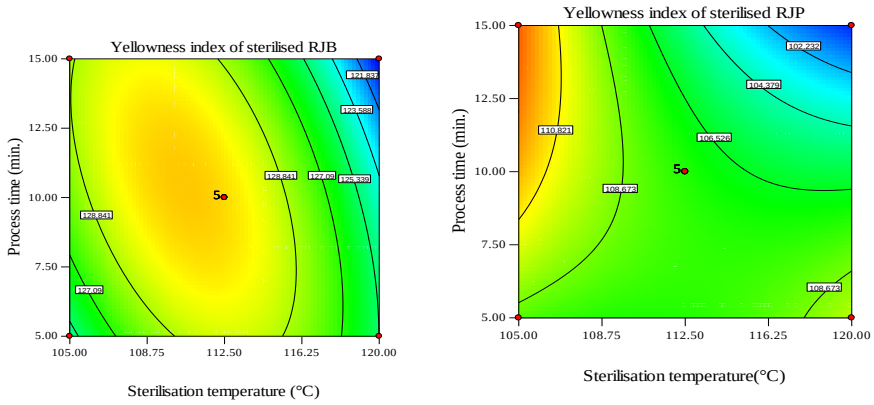
(a) **(b)**

Fig.4.24 ΔE value of retort pouch sterilised ripe jackfruit sample



(a) **(b)**

Fig.4.25 BI of retort pouch sterilised ripe jackfruit sample



(a) **(b)**

Fig.4.26 YI of retort pouch sterilised ripe jackfruit sample

4.2.2.4 Effect of Retort pouch sterilisation on AA of ripe jackfruit

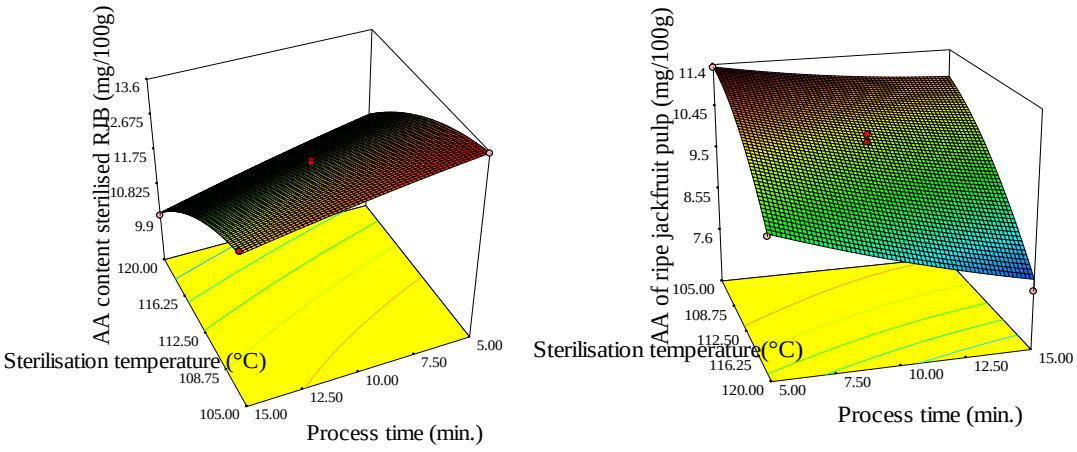
The AA in sterilised RJP ranged from 9.98±0.45 mg/100g to 13.56± 0.62 mg/100g (Fig 4.27b), while in bulb samples, it ranged from 7.83± 0.28 mg/100g to 11.33± 0.40 mg/100g (Fig 4.27a). Prior to sterilisation the fresh values were 13.81± 0.48 mg/100g for bulb samples and 12.45± 0.57 mg/100g for pulp samples. This data suggests that there was a decrease in the AA content of both RJB and RJP samples after sterilisation. The range of values observed in the sterilised samples indicates variability in AA content among different batches or sterilisation conditions. Comparing the AA content of the sterilised samples to the fresh values provides insight into the extent of degradation or loss of AA during sterilisation. In both bulb and pulp samples, the AA content decreased after sterilisation. This reduction in AA content could be due to the heat sensitivity of AA, leading to its degradation during the sterilisation process (Wu *et al.*, 2021).

The statistical analyses for the AA content in both sterilised ripe jackfruit bulb and pulp indicate highly significant models, with respective F-values of 247.89 and 65.03, and p-values < 0.0001, showing very low probabilities of the results being due to noise. For both the bulb and pulp, temperature (T_S) and time (t_s) are significant factors, with temperature being more impactful (F-values: bulb 973.94, pulp 250.37). The quadratic term for temperature (T_S^2) is also significant in both cases, suggesting an optimal temperature range for ascorbic acid retention. The interaction term ($T_S t_s$) is not significant in either model, and the quadratic term for time (t_s^2) is also not significant. Both models demonstrate excellent fits with high R^2 values (RJB= 0.9944, RJP= 0.9789), and their predicted R^2 values are in reasonable agreement with the adjusted R^2 values, confirming strong predictive capabilities (Table B12 and B13). The lack of fit is not significant for either model, indicating a good model fit overall. These findings highlight the critical importance of temperature control in optimizing ascorbic acid content during the sterilisation process for both jackfruit bulb and pulp. The model regression equation in terms of coded form is given below

AA_{RJB} (mg/100g) $= 12.35 - 1.23T_S - 0.53t_s - 0.12T_S t_s - 0.37T_S^2 - 0.049 t_s^2$ … (4.40)

AA_{RJP} (mg/100g) $= 10.14 - 1.21T_S - 0.52t_s - 0.24T_S t_s - 0.38T_S^2 + 0.094 t_s^2$ … (4.41)

Where, AA_{RJB} and AA_{RJP}: Ascorbic acid content of ripe jackfruit bulb and ripe jackfruit pulp respectively and T_s is the sterilisation temperature in ^oC and t_s is the process time in min



(a) **(b)**

Fig.4.27 AA content of retort pouch sterilised ripe jackfruit sample

4.2.2.5 Effect of Retort pouch sterilisation on TPC and TFC of ripe jackfruit

The TPC in sterilised RJP varied from 56.49±2.59 mg GAE/g to 64.85±2.83 mg GAE/g (Fig 4.28b), while in RJB samples, it ranged between 68.51±3.14 mg GAE/g and 58.51±2.11 mg GAE/g (Fig 4.28a). Before sterilisation the fresh phenolic content was measured at 68.53±1.81 mg GAE/g for RJP and 71.11±2.56 mg GAE/g for RJB samples. The observed degradation in TPC following sterilisation was significant, particularly at a temperature of 123°C for 10 min, where a reduction of 16.66% was noted in RJB samples and 17.56% in RJP samples. This substantial decrease in phenolic content could be attributed to the thermal degradation of phenolic compounds during the sterilisation process. These findings underscore the vulnerability of phenolic compounds to heat, suggesting the importance of carefully

considering sterilisation parameters to minimize the loss of these valuable bioactive compounds. The study by Oancea *et al*. (2017) investigated the degradation kinetics of antioxidant activity, flavonoids, and phenolic compounds in sour cherries during thermal processing. The results revealed that the degradation process follows first-order reaction kinetics. Additionally, the study found that increasing the temperature significantly accelerates the degradation of these bioactive compounds, highlighting the importance of temperature control during processing to preserve nutritional quality. Given the potential health benefits associated with phenolic compounds, such as their antioxidant properties, strategies to optimize sterilisation methods while preserving phenolic content may be warranted to ensure the nutritional quality of sterilised ripe jackfruit products.

The TFC in sterilised RJB was found to range from 31.50±1.09 mg RE/g to 38.8±1.03 mg RE/g (Fig 4.29a), indicating a considerable variability within this range. Similarly, in the pulp, the TFC ranged from 14.7±0.67 mg RE/g to 18.56±0.85 mg RE/g, (Fig 4.29b) demonstrating a slightly lower range compared to the bulb. Comparing these figures to the fresh values, we find that the TFC in the fresh bulb was notably higher at 40.12±1.45 mg RE/g, whereas in the fresh pulp, it was 20.33±0.73 mg RE/g. This suggests that the sterilisation process led to a reduction in the TFC in both bulb and pulp samples. Notably, a higher reduction in TFC was observed at a temperature of 120°C for 15 min. This indicates that higher temperatures during sterilisation may have a more pronounced effect on the degradation or alteration of flavonoid compounds. The similarity of these results to those reported in fruit drinks based on milk by Cilla *et al*. (2012) underscores the potential impact of sterilisation methods on the flavonoid content of food products. These findings highlight the importance of optimizing sterilisation parameters to minimize the loss of beneficial flavonoids while ensuring product safety and quality. The ANOVA table suggests that temperature exerted a highly significant ($p<0.0001$) influence on TPC in both jackfruit pulp ($R^2=0.9734$) and bulb ($R^2=0.9822$), with time also contributing significantly ($p<0.05$) (Table B9 and B8). While the models for both

pulp and bulb demonstrated strong overall fit, as indicated by high R^2 values, the lack of fit test for pulp was marginally significant (p=0.0503). The ANOVA for the response surface quadratic model revealed significant effects of sterilisation conditions on TFC in both jackfruit pulp and bulb (Table B11 and B10). For the jackfruit bulb, the model was highly significant (F = 63.90, $p < 0.0001$), with temperature ($p < 0.0001$), time ($p < 0.05$), and the quadratic effect of temperature ($p < 0.0001$) as significant factors influencing flavonoid content. The model exhibited a strong fit ($R^2 = 0.9786$) and adequate prediction (pred $R^2 = 0.9092$). In the jackfruit pulp, the model was also highly significant (F = 25.56, p = 0.0002), with temperature ($p < 0.0001$) and time ($p < 0.05$) as significant factors. Although the model fit was good ($R^2 = 0.9481$), with reasonable predictive ability (pred $R^2 = 0.8658$), the lack of fit was not significant (p = 0.30), indicating a satisfactory model. These findings suggest that the developed models effectively predict TFC in both jackfruit components under the studied conditions. The model regression equation in terms of coded form is given below

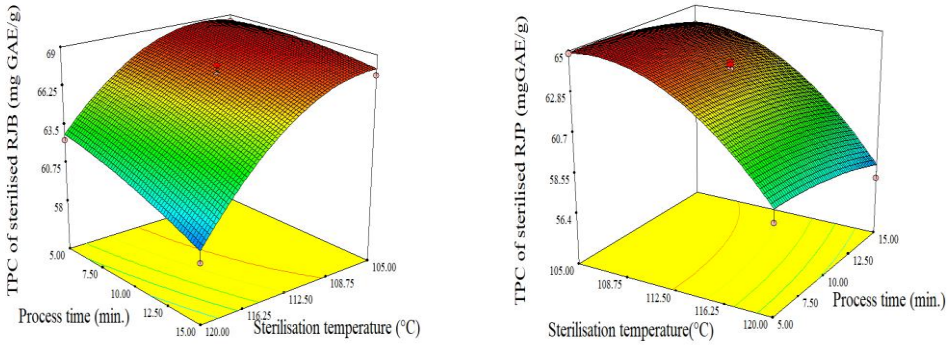
$$TPC_{RJB} \text{ (mg GAE/g)} = 67.35 - 3.62T_S - 1.02t_s - 0.74\,T_S\,t_s - 2.26T_S^2 - 0.39\,t_s^2 \quad \ldots (4.42)$$

$$TPC_{RJP} \text{ (mg GAE/g)} = 63.51 - 3.06\,T_S - 0.61t_s - 0.17T_S\,t_s - 1.79T_S^2 - 0.33t_s^2 \quad \cdots (4.43)$$

$$TFC_{RJB} \text{ ((mg RE/g)} = 37.21 - 2.61T_S - 0.83\,t_s - 0.63T_S\,t_s - 1.22T_S^2 + 0.050\,t_s^2 \quad \ldots (4.44)$$

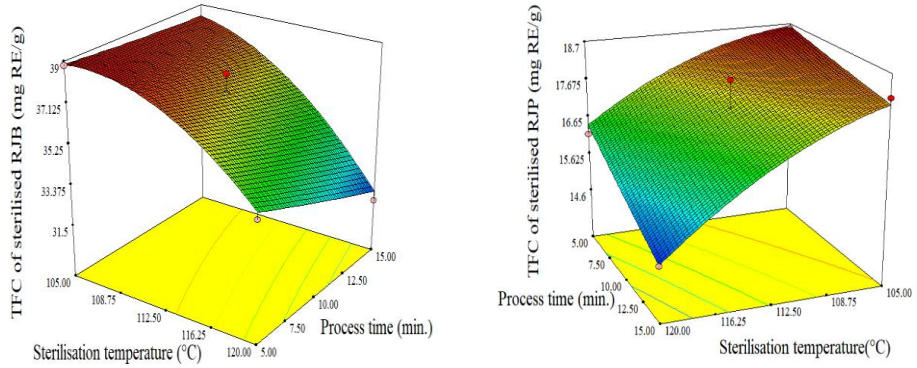
$$TFC_{RJP} \text{ (mg RE/g)} = 17.35 - 1.35T_S - 0.60t_s - 0.26T_S\,t_s - 0.43\,T_S^2 + 0.018\,t_s^2 \quad \ldots (4.45)$$

Where, TPC_{RJB} and TPC_{RJP}: Total phenolic content of ripe jackfruit bulb and ripe jackfruit pulp respectively. TFC_{RJB} and TFC_{RJP}: Total flavanoid content of ripe jackfruit bulb and ripe jackfruit pulp respectively and T_s is the sterilisation temperature in ^oC and t_s is the process time in min



(a) **(b)**

Fig. 4.28 TPC of retort pouch sterilised ripe jackfruit sample



(a) **(b)**

Fig. 4.29 TFC of retort pouch sterilised ripe jackfruit sample

4.2.2.6 Effect of Retort pouch sterilisation on DPPH radical scavenging of ripe jackfruit

The DPPH radical scavenging activity in sterilised RJB ranged from 86.52 ± 3.12% to 82.6 ± 3.79% (Fig 4.30a), while in the RJP, it varied from 82.83 ± 3.80% to 80.48 ± 2.90% (Fig 4.30b). Comparatively, the fresh DPPH radical scavenging activity values were higher, with the RJB measuring at 87.54 ± 2.32% and the RJP at 83.29 ± 3.63%. It's worth noting that a greater reduction in DPPH radical scavenging activity was observed when subjecting the samples to a temperature of 120°C for 15

min during sterilisation. This suggests that higher temperatures and longer sterilisation times could exert a more pronounced effect on the antioxidant activity of both jackfruit bulb and pulp as suggested by Miller and Silva (2012).

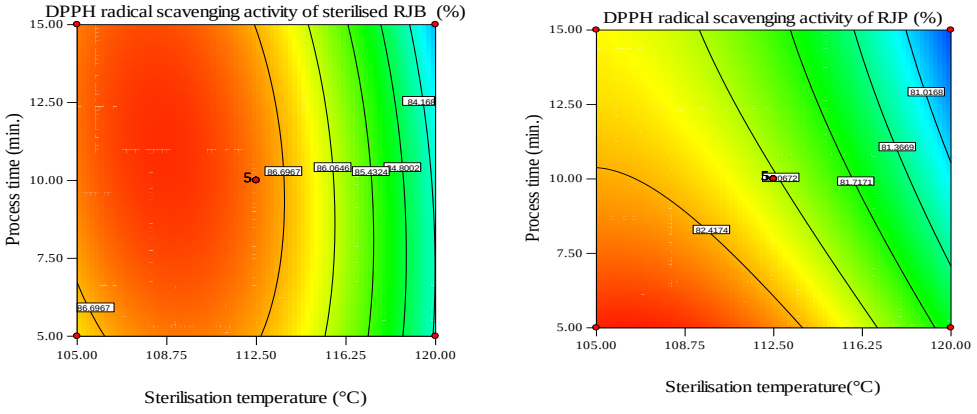
Overall, the decrease in DPPH radical scavenging activity after sterilisation highlights the potential loss of antioxidant compounds, which play a crucial role in protecting cells from oxidative damage. This underscores the importance of carefully considering sterilisation conditions to preserve the antioxidant properties of food products like ripe jackfruit.

The statistical analyses for the DPPH radical scavenging activity content in both sterilised ripe jackfruit bulb and pulp reveal significant models with F-values of 7.14 (RJB) and 35.33 (RJP), and p-values < 0.0001, indicating low probabilities of the results being due to noise. For both bulb and pulp, temperature (T_S) and time (t_s) are critical factors, with temperature having a more substantial impact, as seen in their respective F-values: bulb 19.00 and 16.35, pulp 115.68 and 32.51. The quadratic term for temperature (T_S^2) is significant in both models, indicating an optimal temperature range for maximizing DPPH content. The interaction term (T_S t_s) and the quadratic term for time (t_s^2) are not significant in either model. Both models demonstrate good fits with high R^2values (RJB= 0.8361, RJP= 0.9619), and their predicted R^2 values are in reasonable agreement with the adjusted R^2 values, confirming strong predictive capabilities (Table B26 and B27). The lack of fit is not significant for both models, indicating a good model fit overall. These findings underscore the critical role of temperature control in optimizing DPPH radical scavenging activity during the sterilisation process for both jackfruit bulb and pulp, highlighting the efficiency and effectiveness of the models in guiding optimal sterilisation parameters.The model regression equation in terms of coded form is given below

$$DPPH_{RJB}\ (\%) = 86.95 - 1.44\ T_S - 0.024\ t_s - 0.26\ T_S\ ts - 1.44 T_S^2 - 0.25 t_s^2 \quad \ldots (4.46)$$

$$DPPH_{RJP}\ (\%) = 82.09 - 0.68 T_S - 0.36\ t_s - 0.11\ T_S\ ts - 0.34 T_S^2 + 0.069 t_s^2 \quad \ldots (4.47)$$

Where, $DPPH_{RJB}$ and $DPPH_{RJP}$: DPPH radical scavenging activity of ripe jackfruit bulb and ripe jackfruit pulp respectively and T_s is the sterilisation temperature in ºC and t_s is the process time in min



(a) **(b)**

Fig. 4.30 DPPH radical scavenging activity of retort pouch sterilised ripe jackfruit sample

4.2.2.7 Effect of retort pouch sterilisation on Total sugar content of ripe jackfruit

The analysis of total sugar content in sterilised RJB and RJP under various process conditions reveals that the total sugar content in RJB ranges from 15.8±0.56% to 21.33±0.55% (Fig 4.31a) and in RJP from 13.65±0.59% to 22.56±0.81% (Fig 4.31b). The control values for total sugar content are 21.33±0.56% for RJB and 22.56±0.81% for RJP. Post-processing, the sugar content decreased, with the minimum values being 15.8±0.56% for RJB and 13.65±0.59% for RJP at 120˚C/15 min. A notable trend is that higher temperatures generally reduce the sugar content in both RJB and RJP, likely due to thermal degradation or Maillard reactions (Gonclaves *et al*., 2020). Zhang *et al*. (2022) reported that post sterilisation did not affect much in the total sugar and reducing sugar in jujube juice fermented by *Lactobacillus plantarum*.

The ANOVA results indicate significant models for both RJB and RJP (Table B28 and B29), with F-values of 162.40 and 72.23, respectively, and p-values < 0.0001, confirming the impact of temperature (T_S) and time (t_s) on sugar content. For RJB, the interaction term ($T_S t_s$) and quadratic terms T_S^2 and t_s^2 are also significant. The R^2values of 0.9915 for RJB and 0.9810 for RJP suggest that the models explain a substantial portion of the variability. These findings underscore the importance of optimizing sterilisation conditions to preserve sugar content in sterilised jackfruit products. Final equation in terms of coded factors is given by

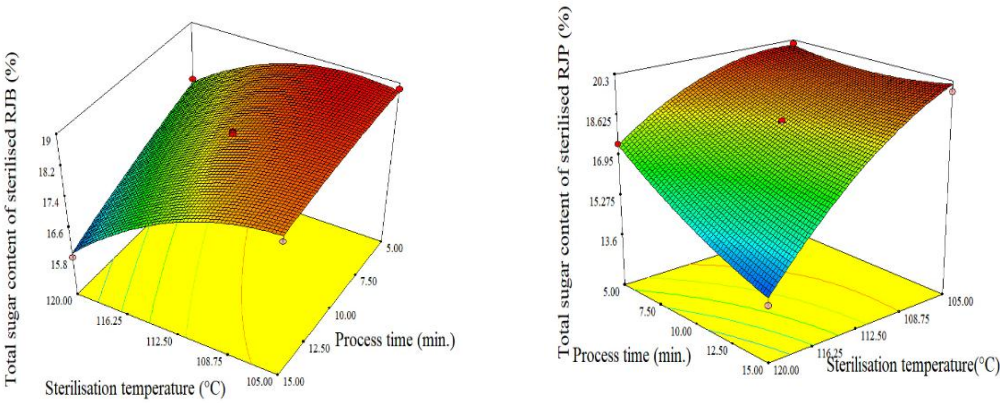
Total Sugar content in RJP (%)

$$= 18.39-2.22\ T_S-0.85t_s\ -0.89T_S\ t_s\ -0.82\ T_S^2+0.32\ t_s^2 \quad \ldots (4.48)$$

Total Sugar content in RJB (%)

$$= 18.32-0.97\ T_S\ -0.47t_s\ -0.30T_S\ t_s\ -0.57\ T_S^2 0.078\ t_s^2 \quad \ldots (4.49)$$

Where, T_s is the sterilisation temperature in ºC and t_s is the process time in min



(a) **(b)**

Fig.4.31 Total sugar content of retort pouch sterilised ripe jackfruit sample

4.2.2.8 Microbial analysis of retort pouch sterilised ripe jackfruit

The microbial analysis of sterilised ripe jackfruit samples revealed that both RJB and RJP showed a significant reduction in microbial population post-sterilisation. According to the National Food Safety Standard for Beverages, the acceptable limit for TAM is less than 2 log CFU/g, and for yeast/mold, it is less than 1.3±0.03 log CFU/g (Wang *et al*., 2019). The control sample indicated initial microbial populations with TAM counts of 4.3±0.15 log CFU/g in RJB and 4.8±0.20 log CFU/g in RJP (Table 4.5), and yeast/mold counts of 4.5 ±0.11 log CFU/g in RJB and 4.8±0.20 log CFU/g in RJP, which were above the standard safety limits, demonstrating a high risk of microbial contamination. Upon sterilisation at various temperatures and durations, total aerobic bacteria were not detected in most RJB and RJP samples, except for a few cases at 105°C and 120°C, where minimal counts were observed. Yeast and mold counts were similarly reduced to non-detectable levels in most samples, with few exceptions at 105°C and 120°C. Notably, at 112.5°C for 10 min, microbial populations in both RJB and RJP were consistently undetectable, indicating that this condition is highly effective for sterilisation. These results highlight the efficacy of the sterilisation process in significantly reducing microbial loads in ripe jackfruit bulb and pulp, ensuring enhanced safety and shelf life of the product. This sterilisation treatment is critical for ensuring the safety and extending the shelf life of the product by effectively killing microorganisms through protein denaturation, metabolic enzyme inactivation, and DNA damage (Zhang *et al*., 2024). Bhat *et al*., 2016 observed similar results in bottle guard juice in which microbial population (bacteria, yeast and mould) was below detection limit.

4.2.2.9 Effect of retort pouch sterilisation on firmness of ripe jackfruit

The analysis of the firmness of ripe jackfruit after retort pouch sterilisation revealed significant variations depending on the temperature and time of treatment. The firmness of the treated samples ranged from 40.15 ± 1.80 N to 53.65 ± 1.93 N. Compared to the control sample, which had a firmness of 54.55 ± 1.44 N, all treated

samples exhibited a reduction in firmness. The treatment with the highest firmness value was at a temperature of 101.89°C for 10 min, yielding a firmness of 53.65 ± 1.93 N, representing a minimal reduction of 1.65% from the control. Conversely, the treatment at 123°C for 10 min resulted in the lowest firmness value of 40.15 ± 1.80 N, indicating a significant reduction of 26.40%. The firmness of the jackfruit decreased with increasing temperature and time. For instance, at 105°C, the firmness was 51.4 ± 1.35 N at 5 min and slightly increased to 52.68 ± 1.40 N at 15 min (Fig 4.32). At 120°C, the firmness decreased from 45.65 ± 1.64 N at 5 min to 42.85 ± 1.13 N at 15 min. This trend highlights the temperature-dependent nature of firmness reduction, with higher temperatures causing more significant softening. The reduction in firmness during retort pouch sterilisation is primarily attributed to the breakdown of cell wall structures and the gelatinization of starches within the fruit. Additionally, heating can lead to the splitting of glycosidic bonds in pectins through β-elimination, resulting in increased pectin solubilization and subsequent texture loss (Ranganathan *et al*., 2015). These factors collectively contribute to the softening of the tissue during thermal processing.

Table 4.5 Microbial analysis of retort pouch sterilised ripe jackfruit samples

Sterilisation temperature (˚C)	Process time (min)	TAM (RJB) (log CFU/g)	TAM (RJP) (log CFU/g)	Yeast/mold (RJB) (log CFU/g)
Control sample		4.3±0.15	4.8±0.20	4.5 ±0.11
105	5	10±0.36	9±0.31	8±0.30
120	5	9±0.32	10±0.38	7.35±0.31
105	15	10±0.31	11±0.41	8.17±0.28
120	15	ND	ND	ND
102	10	8±0.33	7±0.25	6.2±0.21
123	10	ND	ND	ND
112.5	3	8±0.29	8±0.32	6.21±0.18
112.5	17	ND	ND	ND
112.5	10	ND	ND	ND
112.5	10	ND	ND	ND
112.5	10	ND	ND	ND
112.5	10	ND	ND	ND
112.5	10	ND	ND	ND

ND: Not detected

The ANOVA table provided further insights into the effects of temperature and time on the firmness of the jackfruit. Temperature (T_S) was the most significant factor affecting firmness, with an F-value of 230.45 and a p-value of less than 0.0001 and R^2 value of 0.97. Time (t_s) also had a significant impact, with an F-value of 5.58 and a p-value of 0.0502. The interaction between temperature and time ($T_S t_s$) was significant as well, with an F-value of 6.38 and a p-value of 0.0394, indicating that the combined effect of these two factors plays a crucial role in determining the firmness of the jackfruit. In conclusion, the retort pouch sterilisation process significantly affects the firmness of ripe jackfruit, with higher temperatures and longer times leading to greater reductions in firmness. The model regression equation in terms of coded form is given below

$$\text{Firmness (N)} = 50.06 - 4.33T_s - 0.67t_s - 1\ t_s + .02\ T_s\ t_s\ 1.67\ T_s^2 - 0.069t_s^2 \quad \ldots(4.50)$$

Where, T_s is the sterilisation temperature in ºC and t_s is the process time in min

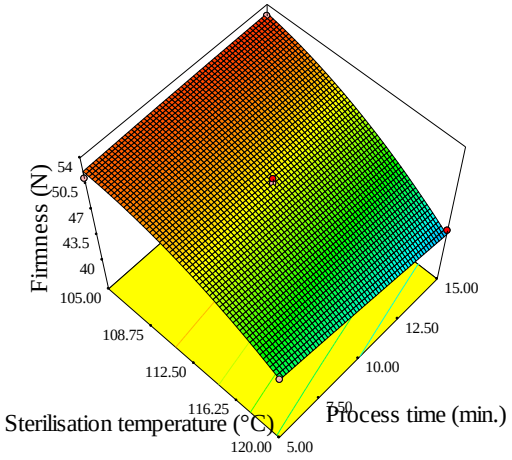


Fig.4.32 Firmness of retort sterilised ripe jackfruit sample

4.2.2.10 Effect of retort pouch sterilisation on rheological property of pulp

The rheological analysis of thermally sterilised ripe jackfruit pulp under varying treatment conditions revealed distinct behaviours in dynamic viscosity. The data indicated that the dynamic viscosity of the pulp was influenced by both the

temperature and the holding time during sterilisation. Specifically, as the temperature and holding time increased, a noticeable reduction in dynamic viscosity was observed, particularly at higher shear rates, suggesting a shear-thinning behavior of the pulp. At lower shear rates, the jackfruit pulp exhibited higher dynamic viscosity values. For instance, at 105°C with a holding time of 5 min the dynamic viscosity was measured at 50.74 ± 0.25 Pa·s. As the shear rate increased the dynamic viscosity decreased significantly to 30.14 ± 0.32 Pa·s, demonstrating the pulp's non-Newtonian, shear-thinning behavior (Fig 4.34) as discussed earlier in pasteurised samples. This trend is consistent with the behavior of many fruit pulps, where molecular interactions are reduced under shear forces, leading to lower resistance to flow. A similar pattern is seen at 120°C and a holding time of 5 min.in RJP. This indicates that increasing shear rate accelerates the breakdown of the pulp's structure, reducing dynamic viscosity (Abdullah *et al*., 2018).

Temperature and holding time played critical roles in influencing the dynamic viscosity of the jackfruit pulp. At 105°C and a holding time of 5 min, the dynamic viscosity was 50.74 ± 0.25 Pa·s but this decreased to 41.76 ± 0.52 Pa·s at 105°C, 15 min. However, at 120 °C and the same holding time (5 min.), dynamic viscosity dropped further to 30.14 ± 0.32 Pa·s. This sharp decline highlights the impact of heat on the molecular structure of the pulp, likely leading to the breakdown of pectin, cellulose, and other structural components (Sato and Cunha 2007).

At higher temperatures, such as 123 °C with a holding time of 10 min, the dynamic viscosity decreased from 51.21 ± 0.23 Pa·s to 27.49 ± 0.41 Pa·s. Fig 4.33 shows that increasing both temperature and holding time can accelerate the reduction in dynamic viscosity, which is important for processes requiring precise control over flow properties. The decrease in dynamic viscosity with increasing temperature can be explained by the enhanced molecular mobility of the pulp constituents, leading to reduced flow resistance. The data supports the shear-thinning behavior of the jackfruit pulp, where the dynamic viscosity decreases as the shear rate increases. This behavior

is typical of non-Newtonian fluids, where increased shear causes alignment of macromolecules such as starches and fibers, resulting in lower dynamic viscosity (Krokida *et al*.,2001).

The ANOVA for the response surface quadratic model of dynamic viscosity data revealed that the model was significant. Among the model terms, temperature and time were highly significant, with p-values of less than 0.0001 and 0.0025, respectively with R^2 value of 0.81 (Table B14). The interaction term and the quadratic terms were not significant, with p-values greater than 0.05, suggesting that they did not contribute significantly to the model. The lack of fit was not significant (p = 0.3166), indicating that the model adequately fits the data. Given the significant terms and the lack of significant lack of fit, the model is reliable in explaining the variation in dynamic viscosity based on temperature and time.

Dynamic viscosity

$$= 37.68-8.81* T_S-4.59 * t_s+1.08* T_S * t_s+0.079* T_S^2+0.77 * t_s^2 \quad \ldots (4.51)$$

Where, T_s is the sterilisation temperature in ^oC and t_s is the process time in min

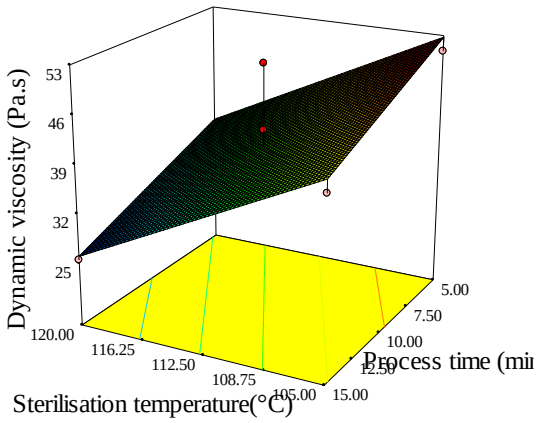
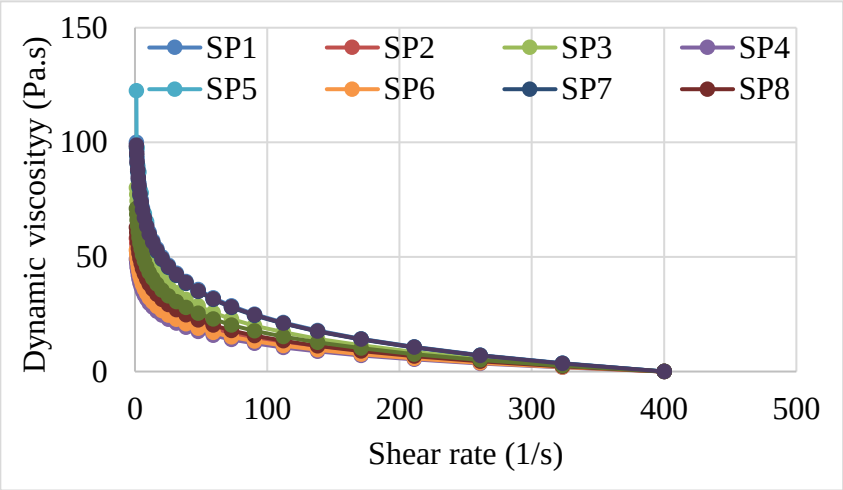


Fig.4.33 Dynamic viscosity of retort sterilised RJP



SP1:105°C/5min., SP2:120°C/5min., SP3:105°C/15min., SP4:120°C/15min., SP5:102°C/10min., SP6:123°C/10min., SP7:112.5°C/3min., SP8:112.5°C/17min.,

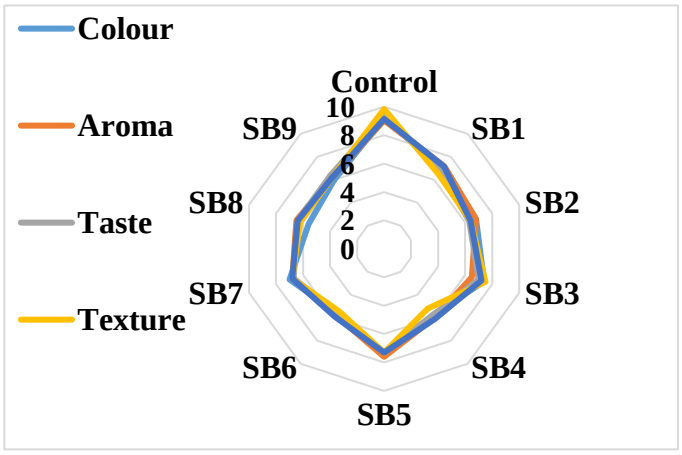
Fig.4.34 Dynamic viscosity vs shear rate of retort pouch sterilised RJP

4.2.2.11 Sensory evaluation of retort pouch sterilised ripe jackfruit

The sensory evaluation of sterilised RJB and RJP was conducted to assess the impact of different sterilisation treatments on key sensory attributes: color, aroma, taste, texture, and overall acceptability. The sensory scores were provided by a panel of trained evaluators, and the results are summarized in the sensory scorecards for both RJB and RJP. The control sample of RJB exhibited the highest sensory scores across all attributes, with particularly high ratings for color (9.21 ± 1.02), aroma (9.04 ± 1.12), taste (9.41 ± 1.03), texture (9.84 ± 1.20), and overall acceptability (9.14 ± 1.04). Among the treated samples, SB1 (105°C, 5 min) and SB3 (105°C, 15 min) showed relatively better scores compared to other treatments. Specifically, SB1 had scores of 7 ± 0.85 for aroma, 7.2 ± 0.47 for taste, 6.8±0.88 for texture, and 7.15 ± 0.74 for overall acceptability, indicating that a moderate sterilisation condition can retain favorable sensory qualities (Fig 4.35). In contrast, SB4 (120°C, 15 min) exhibited the lowest scores for aroma (5.8 ± 1.22), taste (5.8 ± 1.41), texture (5.21 ± 1.04), and overall acceptability (6.1 ± 1.11), suggesting that higher temperatures and prolonged times

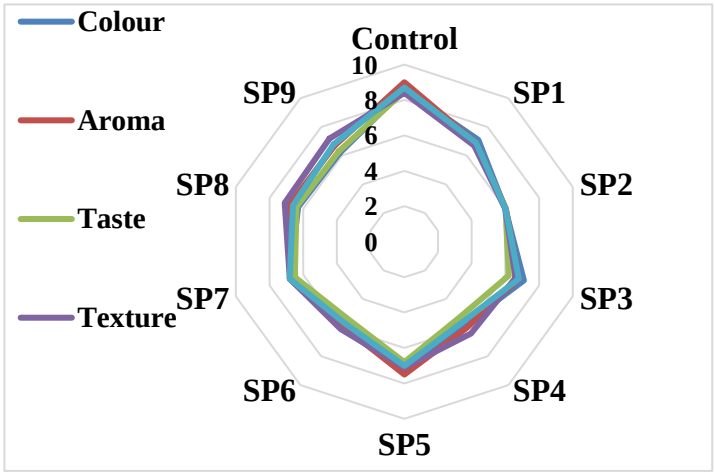
may negatively impact the sensory attributes of jackfruit bulbs. For RJP, the control sample again received the highest scores across all sensory attributes, with notable ratings in aroma (9 ± 1.14), taste (8.5 ± 1.41), texture (8.4 ± 2.01), and overall acceptability (8.7 ± 2.11). Among the treated samples, SP5 (102°C, 10 min) had a relatively high overall acceptability score of 7.01 ± 1.20, indicating a balanced treatment condition that preserves sensory qualities. On the other hand, SP4 (120°C, 15 min) had the lowest scores in aroma (5.8 ± 1.23), taste (5.3 ± 1.25), texture (5.3 ± 1.04), and overall acceptability (5.6 ± 1.44), further emphasizing that high temperatures and extended sterilisation times detrimentally affect the sensory attributes of jackfruit pulp (Fig 4.36). The data suggest that lower to moderate sterilisation temperatures and shorter times generally preserve the sensory qualities of jackfruit bulbs and pulp better than higher temperatures and longer durations. For RJB, the optimal treatment appears to be SP1 (105°C, 5 min) as it balances sensory attributes while maintaining a high level of overall acceptability. Similarly, for RJP, treatment SP5 (102°C, 10 min) emerges as the most favorable, providing a good balance of sensory attributes.

These findings align with previous research indicating that thermal sterilisation parameters significantly influence the sensory and nutritional quality of fruits and vegetables (Ma *et al*, 2020). Specifically, controlled heat treatments can enhance or preserve desirable sensory characteristics while minimizing the degradation of essential nutrients and sensory qualities. By optimizing sterilisation conditions, it is possible to produce sterilised jackfruit products that meet consumer expectations for sensory quality, thereby enhancing their marketability and acceptance. The statistical analysis of sterilised RJB and RJP provides key insights for treatment standardization. ANOVA results indicate that temperature and time significantly impact all sensory attributes (color, aroma, taste, texture, and overall acceptability) ($p < 0.0001$).



SB1:105°C/5min., SB2:120°C/5min., SB3:105°C/15min., SB4:120°C/15min., SB5:102°C/10min., SB6:123°C/10min., SB7:112.5°C/3min., SB8:112.5°C/17min., SB9:112.5°C/10min.

Fig.4.35 Sensory analysis of retort pouch sterilised RJB



SP1:105°C/5min., SP2:120°C/5min., SP3:105°C/15min., SP4:120°C/15min., SP5:102°C/10min., SP6:123°C/10min., SP7:112.5°C/3min., SP8:112.5°C/17min., SP9:112.5°C/10min.

Fig.4.36 Sensory analysis of retort pouch sterilised RJP

4.2.3 Process optimization

The process optimization for sterilised ripe jackfruit bulbs involved determining the optimal combination of sterilisation parameters to achieve desired quality attributes. The analysis indicated that the selected solution presented an ideal set of conditions, including a temperature of 106°C, a sterilisation time of 7 min, and

a pH of 5.02. It was reported that the TSS and TA were set at 21.76 and 0.567, respectively, to ensure the product's sweetness and acidity were within acceptable ranges. The colour parameters (L*, a*, b*) were optimized to maintain the natural appearance of the jackfruit bulb, while undesirable attributes such as ΔE (1.68) and BI (96.48) were minimized. The report also indicated that beneficial attributes like YI (107.21), AA at 13.40 mg/100g, TPC at 68.85 mg GAE/g, TFC at 38.76, mg RE/g DPPH at 86.86%, total sugar at 18.82%, and firmness at 52.42 N were maximized. The overall desirability of this solution was reported to be 0.825, indicating a high degree of suitability and balance among the various quality parameters. The optimal conditions for sterilised RJP were determined to be 106°C for 5 min., yielding a desirability value of 0.956 and for RJB it was 106ºC for 7 min. Under these conditions, the AA, TPC, and TFC reached their peak levels, while microbial load was minimised. It was concluded that this comprehensive optimization ensured that the sterilised ripe jackfruit samples had superior quality, balancing nutritional value, sensory properties, and shelf life.

4.2.4 Cost analysis

The cost analysis and BCR for processed RJB and RJP demonstrate significant profitability potential. The production cost for retort pouch sterilised RJB is approximately ₹211/kg, while the market price of RJB in syrup is around ₹700/kg. This results in a BCR of 3.3, indicating that for every ₹1 spent on production, a return of ₹3.3 is generated, highlighting a substantial profit margin. In contrast, the RJP production cost is Rs 235/kg has a market price of ₹226/kg, also yielding a BCR of 1.13. However, this suggests a smaller profit margin compared to the bulb (Appendix G). Overall, both products are profitable, but the RJB, particularly when sold in syrup, offers significantly higher returns than the pulp.

4.3 Effect of storage on retort pouch pasteurised and sterilised ripe jackfruit samples

Ripe jackfruit samples processed under retort pouch pasteurisation processing were standardised as 80ºC for 5 min, in RJB and 80ºC for 12 min for RJP. Similarly, the retort pouch sterilisation process for ripe jackfruit samples was optimised as 106ºC for 7 min for RJB and 106ºC for 5 min for RJP. In this study, the quality analysis of optimised samples of retort pouch pasteurised and sterilised RJB and RJP was analyzed over a period of 180 days under refrigerated (4 ± 2ºC, Relative humidity:95%) and ambient storage (30± 2ºC, Relative humidity:70%) conditions, respectively. The result and discussion of the shelf-life analysis of the optimised samples are described under this session.

4.3.1 Effect of storage on pH, TA and TSS on retort pouch pasteurised and sterilised ripe jackfruit samples

In this study, the pH values, TA, and TSS of retort pouch pasteurised and sterilised RJB and pulp were analysed over 180 days under refrigerated and ambient storage conditions respectively. The results showed that all three parameters remained stable throughout the storage period, with no significant changes observed.

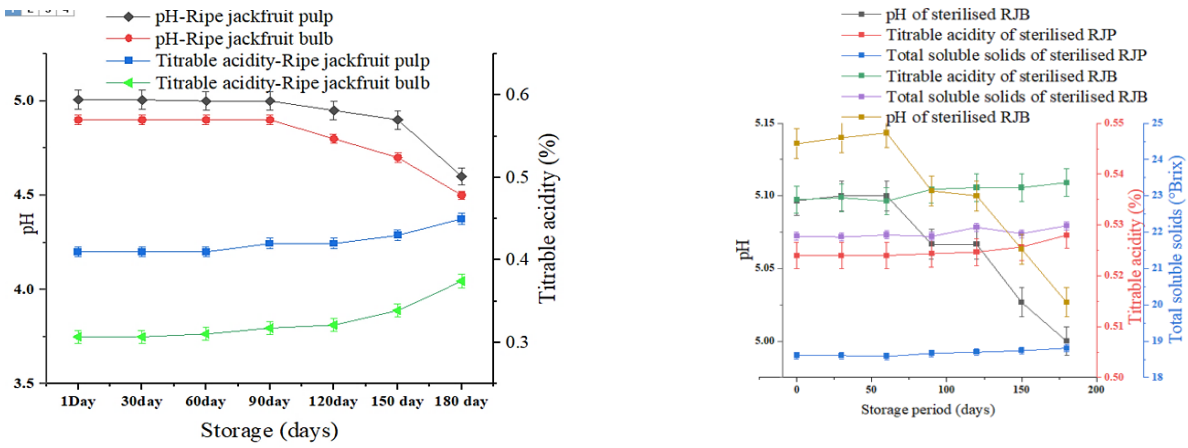
The pH values of sterilised and retort pouch pasteurised RJB and pulp were analysed for 180 days under ambient storage and refrigerated conditions, respectively. For retort pouch pasteurised samples, the pH of freshly prepared RJP remained stable at pH 5 ± 0.22 during refrigerated storage for up to 10 days, before declining to 3.20 ± 0.16, indicating spoilage. In contrast, fresh jackfruit bulbs were stable for up to 15 days, with pH values ranging from 4.82 ± 0.23 to 3.74 ± 0.18 during storage. Retort-processed RJB and RJP showed pH ranges of 4.5±0.21- 4.9 ± 0.17 and 4.6 ± 0.23 - 5.01 ± 0.13, respectively. retort pouch pasteurised jackfruit pulp and bulb exhibited minimal pH variation throughout most of the storage period, with noticeable changes occurring towards the end. The p-value suggests that storage time has a non-significant impact on the pH of retort pouch pasteurised jackfruit pulp, possibly due to microbial activity or chemical changes over time.

In contrast, the pH values of sterilised RJP and RJB remained stable throughout the storage period, with no significant changes observed. The initial pH values of the RJP and RJB were 5.0 ± 0.57 and 4.9 ± 0.18, respectively. After 180 days of storage, the pH values of the RJP ranged from 5.09 ± 0.18 to 5.00 ± 0.23, while the RJB showed pH values ranging from 5.14 ± 0.23 to 5.03 ± 0.18 (Fig 4.37b). Across all treatments, a gradual decrease in pH was observed over 180 days of storage, likely due to mesophilic bacteria metabolizing nutrients such as sugars, producing organic acids, and subsequently lowering the pH (Kaddumukasa *et al*., 2017).

Regarding retort pouch pasteurised samples, the TA of the fresh pulp was initially 0.621 ± 0.11%, increasing to 0.75 ± 0.32 % after 10 days. Similarly, the TA of RJB rose from 0.63 ± 0.03% to 0.68 ± 0.29% after 15 days, leading to bulged packets that were considered spoiled. Concerning retort pouch pasteurised samples, the TA values varied from 0.42 ± 0.03 to 0.59 ± 0.02% in RJB and 0.41 ± 0.02 to 0.62 ± 0.03% in RJP. (Fig. 4 .37a). The TA of the ripe jackfruit samples remained stable during storage, with a slight increase noted after 150 days. There was no significant variation in TA immediately after processing and up to the 90^{th} day. The final increase in acidity can be attributed to a rise in the concentration of weakly ionized acids and their salts during storage. This indicates that storage significantly impacts the TA of retort pouch pasteurised jackfruit pulp, likely due to the formation of organic acids or other biochemical changes during storage (Yi *et al*., 2017). Initially, the sterilised fresh pulp and bulb exhibited similar TA values, with 0.57 ± 0.02% and 0.58 ± 0.02%, respectively. During storage, the TA of the pulp underwent a slight fluctuation, ranging from 0.53 ± 0.01% on day 60 to 0.54 ± 0.11% on day 180. Similarly, the TA of the bulb showed a minor variation, starting at 0.52 ± 0.03% on day 0 and reaching 0.52 ± 0.02% by day 180. Notably, the variation in TA values across the sterilised samples was found to be non-significant, suggesting that the TA remained relatively stable throughout the storage period, with only minor changes occurring.

The TSS content of fresh RJP initially measured 20.60 ± 0.94°Brix, increasing to 21°Brix after 10 days of storage. In retort pouch pasteurised RJB and retort pouch pasteurised RJP, TSS values ranged from 20 to 20.21 ± 0.53°Brix and 19 ± 0.68 to 20.01 ± 0.69°Brix, respectively, over a four-month storage period (Fig 4.38), with a slight,

non-significant increase observed in all samples. Similarly, for the sterilisation process, the initial TSS values for fresh pulp and bulb were 18.5 ± 0.64°Brix and 21 ± 0.96°Bix, respectively, and during storage, the TSS of the pulp ranged from 18.56 ± 0.49°Brix to 18.83 ± 0.65°Brix, while the TSS of the bulb ranged from 21.90 ± 0.62°Brix to 22.16 ± 0.64°Brix. All treatments exhibited a slight increase in TSS throughout the storage period. This modest rise in TSS is likely due to the hydrolysis of polysaccharides into sugars. Similar observations were reported by Muhammad *et al*. (2011) in apple pulp. As presented in Fig., the data indicate that TSS increased in all samples under storage conditions, suggesting that prolonged storage results in higher soluble solids in fruits due to the ongoing conversion of organic acids into starch and sugar through gluconeogenesis (Johari *et al*., 2023). Overall, the storage duration did not significantly affect the TSS content of the retort pouch pasteurised and sterilised jackfruit pulp, suggesting that the sugar content remains stable during storage.



(a) **(b)**

Fig. 4.37 Effect of storage on pH and TA on retort pouch pasteurised and pH, TA and TSS of retort pouch sterilised ripe jackfruit samples respectively

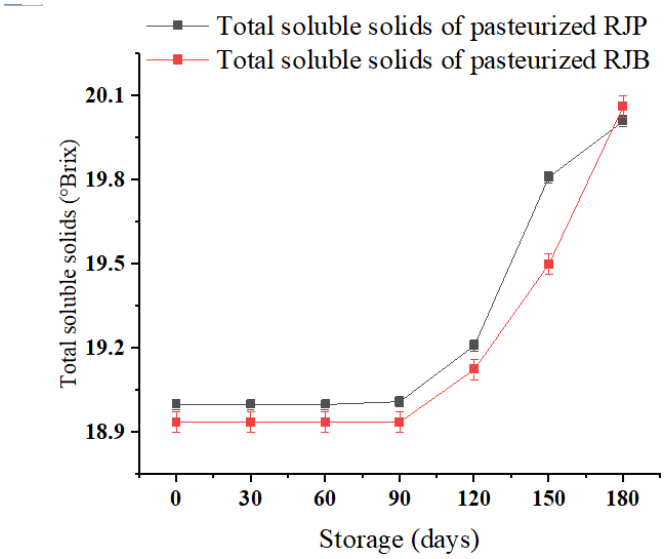


Fig. 4.38 Effect of storage on TSS of retort pouch pasteurised ripe jackfruit samples

4.3.2 Effect of storage on ΔE value on retort pouch pasteurised and sterilised ripe jackfruit samples

The ΔE value was a critical index to evaluate the colour change. The ΔE of fresh RJP increased to 5.8 ± 1.29 and 5.3 ± 1.82 in fresh RJB following 15 days of storage. The changes in ΔE of retort pouch pasterurised ripe jackfruit samples during 180 days of refrigerated storage were presented in Fig 4.39. The research study on the storage of retort pouch pasteurised RJB and RJP indicated notable changes in colour deviation over time. For RJB, it was reported that the initial colour deviation values remained relatively stable, with values of 2.30±1.70 on the 0^{th} and 30^{th} days and a slight increase to 2.40 ± 1.29 on the 60^{th} day. However, a significant deviation began from the 90^{th} day (3.05 ± 1.11), further increasing to 3.50 ± 0.86 on the 120^{th} day, 4.20 ± 1.71 on the 150^{th} day, and reaching the highest deviation of 5 ± 1.56 on the 180^{th} day. Similarly, for RJP, the colour deviation reportedly started at 1.61 ± 1.02 on the $0t^{h}$ day, showing minor changes up to the 90^{th} day with values of 1.62 ± 1.23, 1.63 ± 1.31, and 1.73 ± 0.85, respectively. A marked deviation was observed from the 120^{th} day (2.52 ± 1.65), which significantly increased to 3.82 ± 1.13 on the 150^{th} day, and peaked at 4.27 ± 1.71 on the

180th day. The homogeneous subsets analysis confirmed that the changes in colour deviation for both RJB and RJP were statistically significant ($p<0.05$) only after prolonged storage, with significant differences emerging after the 90th day. This analysis underscored a clear trend of increasing colour deviation with extended storage time, highlighting the impact of storage duration on the quality of retort pouch pasteurised jackfruit bulbs and pulp.

The findings showed that treated jackfruit samples exhibited a darker colour compared to untreated samples, a trend also observed in studies on kiwi fruit juice (Xu *et al*., 2023). Additionally, Yi *et al*. (2017) noted an increase in ΔE values in apple juice following treatment with thermal pasteurisation.

The analysis of total colour deviation in sterilised RJB and RJP during 180 days of ambient storage revealed a range of colour deviations from 6.00 ± 0.27 to 6.31 ± 0.07 for the pulp and from 2.17 ± 1.29 to 2.25 ± 0.10 for the bulb, as measured from the 0th day to the 180th day, respectively. The ANOVA results indicated no significant ($p<0.05$) differences between the groups for both the pulp and bulb samples, with F-values of 0.251 and 0.015 and corresponding p-values of 0.951 and 1.000, respectively. The Duncan multiple range test further confirmed the lack of significant differences in colour deviation across different storage periods. These findings suggest that the sterilised RJP and RJB maintained consistent colour stability throughout the 180-day ambient storage period. Chang *et al*. (2017) found no significant changes in ΔE values for thermally treated white grape juices during a 20-day storage period, whereas the ΔE values for retort pouch pasteurised pineapple juice increased noticeably after 21 days.

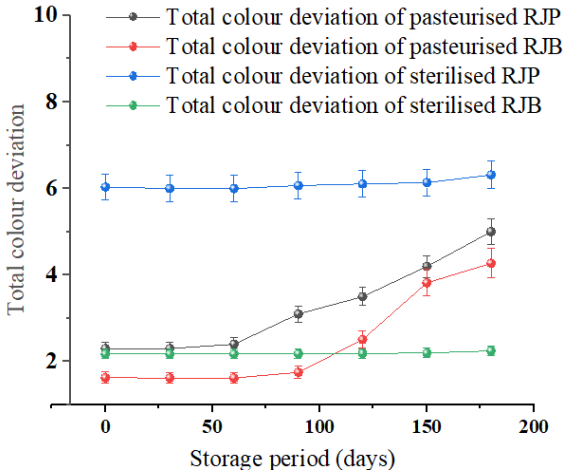


Fig.4.39 Effect of storage on ΔE on retort processed ripe jackfruit samples

4.3.3 Effect of storage on AA of retort pouch pasteurised and sterilised ripe jackfruit amples

The AA content of RJB and RJP decreased significantly over a 180-day storage period, regardless of whether they were retort pouch pasteurised or sterilised. The AA content of the fresh pulp was 10.32 ± 0.27 mg/100 g, which decreased to 6.28 ± 0.19 after 10 days of refrigerated storage, whereas for RJB, it decreased from 14.43 ± 0.52 to 8.45 ± 0.30 mg/100 g after 15 days. The effect of the storage period at refrigerated conditions for 180 days on the AA content of ripe jackfruit samples was found to be significant. In retort pouch pasteurised RJB, the AA content decreased from 14.09±0.64 mg/100 g to 12.91 ± 0.46 mg/100 g, while in sterilised RJB, it decreased from 13.11 ± 0.57 mg/100 g to 10.62 ± 0.49 mg/100 g. Similarly, in retort pouch pasteurised RJP, the AA content decreased from 9.90 ± 0.43 g/100 g to 6.32 ± 0.27 mg/100 g (Fig. 4.40), while in sterilised RJP, it decreased from 11.03 ± 0.38 mg/100 g to 8.75 ± 0.23 mg/100 g.

Regarding retort pouch pasteurised RJP, the analysis revealed that the AA content showed notable stability in the initial storage days, with values of 9.90 ± 0.43 mg/100g on the 0^{th} day and 9.85 ± 0.45 mg/100 g on the 60^{th} day. However, a significant decrease was observed from the 90^{th} day, continuing to decline to 8.25 ± 0.21 mg/100 g on the 120^{th} day, 7.58 ± 0.34 mg/100 g on the 150^{th} day, and reaching the lowest value of 6.32 ± 0.28 mg/100 g on the 180^{th} day. In the case of RJB, the initial AA content was

also relatively high, starting at 14.09 ± 0.61mg/100 g on the 0th day and 14.05 ± 0.52 mg/100 g on the 60th day. The AA content then showed a marked decline, dropping to 13.67±0.62 mg/100 g on the 90th day and 13.65 ± 0.49 mg/100 g on the 120th day. This downward trend continued, with values of 13.26 ± 0.60 mg/100 g on the 150th day and 12.91 ± 0.44 mg/100 g on the 180th day, indicating a significant reduction over the storage period.

The analysis revealed that the AA content of sterilised RJB showed notable stability in the initial storage days, with values of 13.11 ± 0.57 mg/100 g on the 0th day and 13.12 ± 0.60 mg/100 g on the 60th day (Fig 4.41). However, a significant decrease was observed from the 90th day (12.84 ± 0.33 mg/100 g), continuing to decline to 12.65 ± 0.45 mg/100 g on the 120th day, 12.06 ± 0.42 mg/100 g on the 150th day, and reaching the lowest value of 10.62 ± 0.38 mg/100 g on the 180th day. In the case of RJP, the initial AA content was also relatively high, starting at 11.03 ± 0.29 mg/100 g on the 0th day and 10.87 ± 0.45 mg/100 g on the 60th day. The AA content then showed a marked decline, dropping to 10.87±0.49 mg/100g on the 90th day and 10.87 ± 0.50 mg/100 g on the 120th day. This downward trend continued, with values of 9.72 ± 0.25 mg/100 g on the 150th day and 8.75 ± 0.38 mg/100 g on the 180th day, indicating a significant reduction over the storage period.

In both retort pouch pasteurised and sterilised samples, the AA content remained relatively stable during the initial storage days, but began to decline significantly after the 90th day. The rate of decline was more pronounced in retort pouch pasteurised samples, with a 29.38% reduction in RJP and a 10.50% reduction in RJB over the 180-day storage period. In sterilised samples, the reduction was 19.38% in RJP and 10.50% in RJB. The study demonstrates that storage time has a significant impact on the nutritional quality of RJB and pulp, with significant degradation occurring after the initial three months of storage. This reduction in AA content may be due to oxidation in the presence of oxygen by enzymatic catalyst (Jawaheer *et al*., 2003).

4.3.4 Effect of storage on TPC of retort pouch pasteurised and sterilised ripe jackfruit samples

The research investigated the impact of storage time on TPC in retort pouch pasteurised and sterilised RJB and RJP. The research study on the storage of retort pouch pasteurised RJB and RJP analysed the changes in TPC over time, yielding significant insights into the degradation patterns. The control sample (fresh bulb) with a TPC of 71.11 ± 2.56 mg GAE/g decreased to 66.41 ± 2.39 mg GAE/g in 15 days, showing a variation of 6.60%. The fresh pulp with a TPC of 68.53 ± 2.47 mg GAE/g decreased to 55.14 ±1.98 mg GAE/g in 10 days, showing a variation of 15.16%. For RJB, the TPC values during the 180 days of storage ranged from 70.55 ± 3.07 mg GAE/g to 64.24 ± 2.31mg GAE/g , compared to the control sample, representing a reduction of approximately 9.66%. For RJP, the TPC values ranged from 65.11 ± 1.72 mg GAE/g to 57.82 ± 2.52 mg GAE/g over the storage period, compared to the control sample, indicating a reduction of approximately 15.64%.

Statistical analysis through ANOVA for RJB indicated a significant effect of storage time on TPC. The initial TPC values for RJB were relatively stable, starting at 70.53 ± 1.86 mg GAE/g on the 0^{th} day and 70.55 ± 3.23 mg GAE/g on the 30^{th} day. However, a noticeable decline began by the 120th day (69.27 ± 2.49 mg GAE/g), and this trend continued, dropping to 66.52 ± 3.04 mg GAE/g on the 150^{th} day and further to 64.24 ± 2.80 mg GAE/g on the 180^{th} day.

In the case of RJP, ANOVA results showed an even more pronounced impact of storage time on TPC. The initial TPC values were 65.11 ± 1.72 mg GAE/g on the 0^{th} day and 65.10 ± 1.71mg GAE/g on the 30^{th} day, maintaining relative stability until the 60^{th} day (65.02 ± 1.72 mg GAE/g). However, from the 90^{th} day onwards, there was a marked decrease, with TPC values dropping to 64.83 ± 1.24 mg GAE/g, followed by 63.73 ± 2.92 mg GAE/g on the 120^{th} day. The most significant reductions were observed on the 150^{th} and 180^{th} days, with TPC values of 58.45 ± 1.54 mg GAE/g and 57.82 ± 2.64 mg GAE/g , respectively.

Sterilisation also had a notable effect on TPC. The TPC of sterilised jackfruit pulp decreased from 68.53 ± 3.14 mg GAE/g to 42 ±1.51 mg GAE/g over the first three

days of storage, representing an 38.6% loss (Fig 4.40). The TPC of the pulp ranged from 56.93 ± 2.05 mg GAE/g on the 180th day to 64.03± 2.30 mg GAE/g on the 0^{th} day, indicating an 11.1% loss. The bulb, which started with a TPC of 70.11 ± 3.21 mg GAE/g, decreased to 54 ± 1.42 mg GAE/g in the first three days, representing a 23.1% loss, and ranged from 61.79 ± 1.63 mg GAE/g on the 180^{th} day to 68.06 ± 3.11mg GAE/g on the 0^{th} day, indicating a 9.2% loss. These findings suggest that ambient storage significantly reduces TPC in both sterilised pulp and bulb, highlighting the impact of prolonged storage on the phenolic content.

The observed reduction in TPC during storage for both RJB and RJP can be attributed to the oxidation of phenolic compounds, which is likely accelerated by the presence of oxygen and enzymatic activity during prolonged storage (Xu *et al*., 2016). Similarly, the total phenolic content in pasteurised mango pulp also reduced with storage due to the oxidation degradation of phenolic compounds and the polymerization of phenolic compounds with proteins (Kaushik *et al*., 2016)

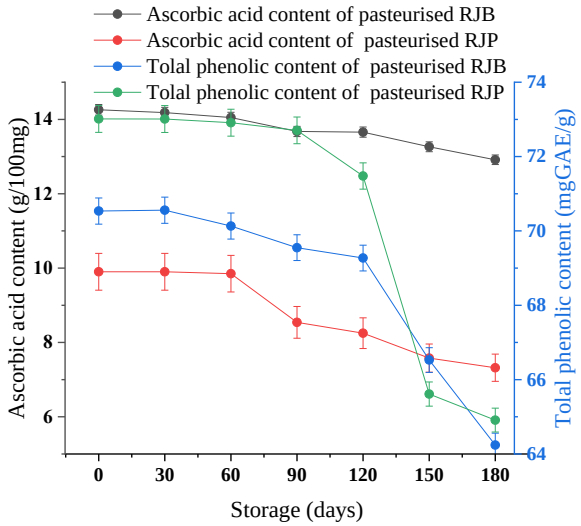


Fig.4.40 Effect of storage on AA and TPC on retort pouch pasteurised ripe jackfruit samples

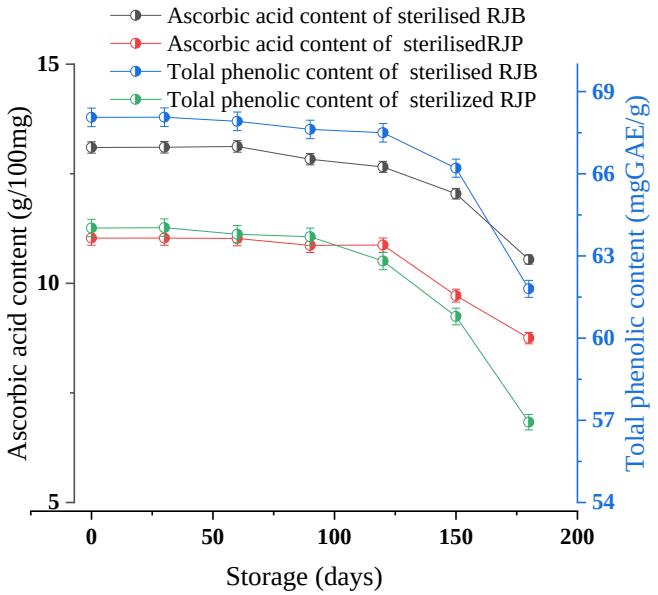


Fig. 4.41 Effect of storage on AA and TPC on retort pouch sterilised ripe jackfruit samples

4.3.5 Effect of storage on total sugar content of retort pouch pasteurised and sterilised ripe jackfruit samples

The total sugar content in pasteurised RJB ranged from 19.87 ± 0.86 to 20.84 ± 0.72%, while for RJP, it ranged from 21.29 ± 0.76 to 23.44 ± 0.62%. The total sugar content in RJB initially showed stability with values of 19.87 ± 0.86% on the 0th day, 19.88 ± 0.86% on the 30th and 60th days, and a slight increase to 20.05 ± 0.72% on the 90th day. This trend continued with values reaching 20.45 ± 0.54% on the 120th day, 20.72 ± 0.74% on the 150th day, and 20.84 ± 0.75% on the 180th day. For RJP, the total sugar content started at 21.29 ± 0.76% on the 0th day, remained similar at 21.29 ± 0.76% on the 30th day, and slightly increased to 21.42 ± 0.56% on the 60th day. The upward trend persisted with values rising to 21.52 ± 0.98% on the 90th day, 21.62 ± 0.99% on the 120th day, 22.61 ± 1.01% on the 150th day, and peaking at 23.44 ± 10.2% on the 180th day. The control sample (fresh pulp) with total sugar content of 22.56 ± 1.03% increased to 23.11 ± 0.83% in 10 days, and 21.33 ± 0.76% in control (fresh bulb) increased to 21.95 ± 0.95% in 15 days. The statistical analysis of total sugar content in pasteurised RJB and RJP during storage revealed notable variations.

The analysis of total sugar content in sterilised RJB and RJP during 180 days of ambient storage revealed a range from 20.07 ±0.69% to 20.14 ± 0.53% and from 18.75 ± 0.85% to 18.82 ± 0.49%, respectively (Fig. 4.42). The ANOVA results indicated no significant difference in total sugar content among the storage days for both samples, with p-values of 1.000 in both analyses. Specifically, the total sugar content in the pulp showed a slight variation, with the mean values recorded as 20.07 ± 0.71% on the 0^{th} and 60^{th} days, 20.08 ± 0.53% on the 30^{th} day, 20.10 ± 0.72% on the 90^{th} day, 20.11±0.53% on the 120^{th} day, 20.12 ± 0.53% on the 150^{th} day, and 20.14 ± 0.87% on the 180^{th} day. For the bulb, the mean values were 18.75 ± 0.51% on the 0^{th} day, 18.77 ± 0.86% on the 60^{th} day, 18.77 ± 0.49% on the 30^{th} day, 18.79 ± 0.86% on the 90^{th} day, 18.80 ± 0.67% on the 150^{th} day, 18.81 ± 0.86% on the 120^{th} day, and 18.82 ± 0.88% on the 180^{th} day. The Levene's test for homogeneity of variances for the bulb indicated a significant result with a p-value of 0.023, suggesting some variability in sugar content consistency. However, the homogeneous subsets analysis using Duncan's multiple range test confirmed that the storage days did not significantly differ in total sugar content at the 0.05 significance level, with the subsets showing p-values of 0.955 and 0.959 for the pulp and bulb, respectively. These findings suggest that the total sugar content in both sterilised RJP and bulb remains stable over a 180-day period under ambient storage conditions.

Over a five-month storage period, the total sugar content in the soft bulb type jackfruit pulp from the Western Ghats increased to 20.93%. This increase could be attributed to the conversion of some acids into sugars. Similar findings have been reported in other fruits: Kavya (2014) observed an increase in the total sugar content of custard apple, Hiremath *et al*. (2012) documented this phenomenon in sapota.

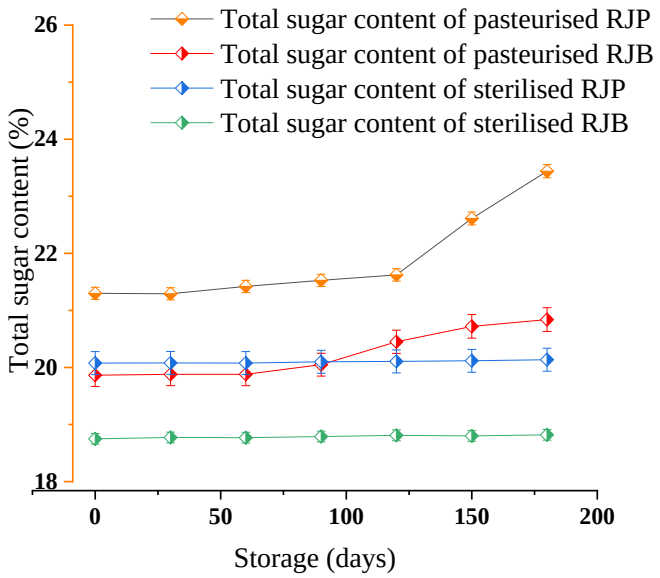


Fig.4.42 Effect of storage on total sugar content of retort pouch pasteurised and sterilised ripe jackfruit samples

4.3.6 Effect of storage on microbial activity of retort pouch pasteurised and sterilised ripe jackfruit samples

The microbial analysis of retort pouch pasteurised RJP and RJB during refrigerated storage revealed distinct patterns in the TAM and yeast and mold populations. In the control sample of jackfruit pulp, the TAM increased from 5.1 ± 1.30 log CFU/g on day 0 to 8.60 ± 1.83 log CFU/g by day 10, resulting in spoilage by day 15. In contrast, the retort pouch pasteurised RJP showed no detectable microbial growth (<1 log CFU/g) up to 60 days of storage (Table 4.6). However, TAM began to rise to 1.55 ± 1.07 log CFU/g at 90 days, reaching 3.14 ± 1.08 log CFU/g by 180 days. Similarly, yeast and mold populations were not detectable in the retort pouch pasteurised pulp up to 60 days, but increased to 1.43 ± 1.06 log CFU/g at 90 days and 3.05 ± 5.19 log CFU/g at 180 days. In the control sample of jackfruit bulb, the TAM increased from 4.8±1.21 log CFU/g on day 0 to 5.62±1.14 log CFU/g by day 15. In contrast, the retort pouch pasteurised RJB exhibited no detectable microbial growth (<1 log CFU/g) up to 90 days of storage. TAM began to increase to 1.31±1.04 log CFU/g at 120 days and reached 2.48 ± 1.08 log CFU/g by 180 days. Yeast and mold populations

in the retort pouch pasteurised bulb were also undetectable up to 90 days but increased to 1.17 ± 1.05 log CFU/g at 120 days and reached 2.17 ± 1.07log CFU/g at 180 days.

The microbial analysis of retort sterilised RJP and RJB during ambient storage was conducted to determine the TAM and yeast and mold counts (log CFU/g) over various storage periods. The control samples exhibited significant microbial growth, with the pulp showing an initial TAM of 4.6 ± 1.02 log CFU/g and yeast and mold count of 4.5 ± 1.11 log CFU/g. By day 3, these values increased to 20.60 ± 1.94 log CFU/g and 21.23 ± 1.56 log CFU/g, respectively, and for RJB it was 4 ± 1.14 and 4.1 ± 1.15 log CFU/g, which increased to 16.24 ± 0.74and 18.41 ± 1.48 log CFU/g, the sample was spoiled after 3 days (Table 4.7). In contrast, the sterilised RJP displayed TAM and yeast and mold counts of less than one log CFU/g from 0 to 150 days, with slight increases to 1.33 ± 1.06 and 1.16 ± 1.053 log CFU/g at 180 days.

Similarly, the control jackfruit bulb exhibited initial TAM and yeast and mold counts of 4.4 ± 1.20 log CFU/g and 4.2 ± 1.15 log CFU/g, which rose to 12.52 ± 1.57 log CFU/g and 15.48 ± 1.78 log CFU/g by day 3. The sterilised bulb samples maintained TAM and yeast and mold counts of less than 1 log CFU/g from 0 to 150 days, with minor increases to 1.02 ± 1.02 and 1.23 ±1.04 log CFU/g at 180 days.

The results are consistent with findings from other studies. For instance, Wu *et al*. (2021) reported an increase in TAM in TP-treated pineapple juices, reaching 1.85 log CFU/mL after 28 days of storage, with undetectable yeast and mold and coliform counts for the first 21 days. Similarly, Monteiro *et al*. (2005) observed that passion fruit pulp retort pouch pasteurised at 70°C maintained yeast and mold and aerobic psychrophilic counts below 10 CFU/mL for up to 180 days of storage, followed by two log cycles of growth from 198 to 207 days. Additionally, Monteiro *et al*. (2005) evaluated the microbiological quality of passion fruit pulps retort pouch pasteurised at 70°C, 75°C, and 80°C, finding that all pulps were suitable for consumption for up to 180 days under refrigeration.

According to the Food Safety and Standards Authority of India (FSSAI), the acceptable limit for TAM in ready-to-eat foods is generally up to 5 log CFU/g, and for yeast and mold, it is up to 3 log CFU/g. Based on these standards, the retort pouch

pasteurised jackfruit pulp and bulb were safe for consumption up to 150 days of storage. Beyond this period, the increase in microbial counts, especially in yeast and mold populations, suggests that the products may not be safe for consumption due to potential spoilage and safety concerns. The results indicate that retort sterilisation effectively reduced microbial loads in both jackfruit pulp and bulb, ensuring microbial stability and safety for up to 180 days under ambient storage conditions. The slight increase observed at 180 days suggests minimal microbial activity, but the overall log reduction confirms the efficacy of the sterilisation process in preserving the quality and safety of the jackfruit products.

Table 4.6 Effect of storage on microbial activity of retort pouch pasteurised ripe jackfruit samples

Sample	storage period (days)	Total aerobic mesophiles (log CFU/g)	Yeast and mold (log CFU/g)
Control sample (Fresh pulp)	0	5.1 ± 1.30^{a}	5.3 ± 2.15^{a}
	10	8.60 ± 1.83^{a}	7.43 ± 3.14^{a}
	15	spoiled	Spoiled
Retort pouch pasteurised RJP	0	<1	<1
	30	<1	<1
	60	<1	<1
	90	1.55 ± 1.07^{a}	1.43 ± 1.06^{a}
	120	1.81 ± 1.02^{a}	1.72 ± 0.95^{a}
	150	1.88 ± 1.35^{b}	2.16 ± 1.4^{a}
	180	3.14 ± 1.08^{b}	3.05 ± 5.19^{a}
Control sample (Fresh bulb)	0	4.8 ± 1.21^{a}	4.6 ± 1.02^{a}
	10	5.24 ± 2.05^{a}	5.30 ± 2.07^{a}
	15	5.62 ± 1.14^{a}	6.43 ± 1.35^{a}
Retort pouch pasteurised RJB	0	<1	<1
	30	<1	<1
	60	<1	<1
	90	<1	<1
	120	1.31 ± 1.04^{a}	1.17 ± 1.05^{a}
	150	2.01 ± 1.85^{a}	2.39 ± 1.25^{a}
	180	2.48 ± 1.08^{c}	2.17 ± 1.07^{c}

Table 4.7 Effect of storage on microbial activity of retort pouch sterilised ripe jackfruit

Samples	storage period	TAM (log CFU/g)	Yeast and mold (log CFU/g)
Control sample (Fresh pulp)	0	4.6 ± 0.02[a]	4.5 ± 0.11[a]
	3	20.60 ±1.94[a]	21.23 ± 1.56[a]
Sterilised RJP	0	<1	<1
	30	<1	<1
	60	<1	<1
	90	<1	<1
	120	<1	<1
	150	1.33 ± 1.06[a]	1.16 ± 1.05[a]
	180	1.14 ± 1.25[a]	1.05 ± 1.87[a]
Control sample (Fresh bulb)	0	4.4 ± 1.20[a]	4.2 ± 1.15[a]
	3	12.52 ± 1.57[a]	15.48 ± 1.78[a]
Sterilised RJB	0	5.62±1.11[a]	6.43 ± 2.35[a]
	30	<1	<1
	60	<1	<1
	90	<1	<1
	120	<1	<1
	150	<1	<1
	180	1.02 ± 1.02[a]	1.23 ± 1.04[a]

4.3.7 Effect of storage on firmness of retort pouch pasteurised and sterilised RJB

The firmness of the jackfruit bulbs was significantly affected by the storage period and the processing method. The control sample (fresh RJB) showed the highest firmness (55.46 ± 2.54 N) at the beginning of the storage period, but it decreased steadily with increasing storage time. At the end of the 180 days storage period, the firmness of the control sample dropped to 48.25 ± 2.38 N, representing a 12.97%

reduction in firmness. The retort pouch pasteurised RJB showed an initial firmness of 54.55 ± 2.49 N, which is slightly lower than the control sample. The firmness decreased to 48.18 N after 180 days, exhibiting a reduction of 11.66% in firmness. The sterilised RJB showed the lowest initial firmness of 51.24 ± 2.42 N. It maintained a relatively stable firmness throughout the storage period, dropping to 49.65 ± 2.27 N after 180 days, demonstrating a mere 3.1% reduction in firmness (Fig 4.43). Overall, the results indicate that the storage period had a significant effect on the firmness of all three samples, leading to a decrease in firmness over time. The pasteurisation process slightly lowered the initial firmness compared to the fresh sample, but resulted in a slightly less significant decrease in firmness over time compared to the fresh sample. Notably, the sterilised jackfruit bulb exhibited the slowest rate of firmness reduction, indicating its superior preservation of firmness throughout the storage period.

The statistical analysis of the retort pouch pasteurised and sterilised jackfruit bulb data revealed distinct patterns. For retort pouch pasteurised bulbs, the ANOVA test indicated a significant difference in firmness across different storage times, suggesting that storage time had a significant impact on firmness. In contrast, the ANOVA test for sterilised bulbs showed no significant difference in firmness across storage times, indicating that the sterilisation process maintained consistent firmness levels regardless of storage time. Additionally, the Levene's test for homogeneity of variances showed that the variances of firmness were not significantly different for both retort pouch pasteurised and sterilised bulbs. Overall, the analysis highlights the importance of considering the effects of storage time and processing methods on the quality of jackfruit bulbs.

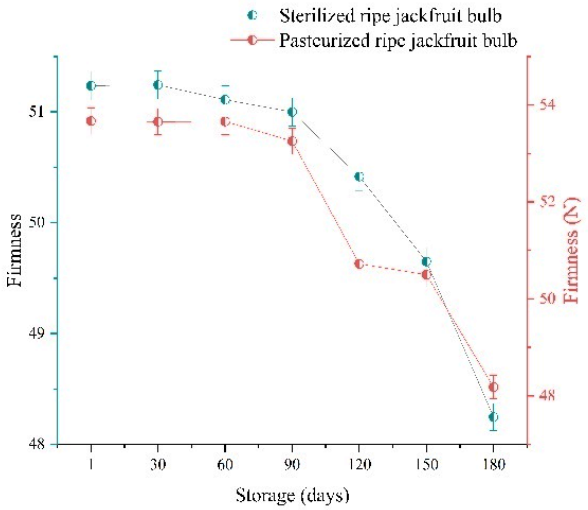


Fig 4.43 Effect of storage on firmness of retort pouch pasteurised and sterilised RJB

4.3.8 Effect of storage on sensory characteristics of retort pouch pasteurised and sterilised ripe jackfruit samples

The study on the sensory evaluation of retort pouch pasteurised RJB and RJP during storage yielded promising initial results, showcasing high acceptability and quality. On day 1, RJB demonstrated excellent overall acceptability with a score of 7.8 ± 0.22, and notable scores in colour (7.4 ± 0.33), aroma (7.2 ± 0.25), and consistency/texture (7.7±0.20). Similarly, RJP started with an overall acceptability score of 7 ± 0.08, with colour, aroma, and consistency/texture scoring 7 ± 0.25, 7 ± 0.18, and 7.1 ± 0.30, respectively. These high initial scores highlight the effectiveness of the retort pouch processing method in preserving the sensory qualities of jackfruit products. However, a declining trend in sensory scores was observed over the six-month storage period. For RJB, the decrease in colour score from 7.4 ± 0.35 to 6 ± 0.27 can be attributed to pigment degradation and potential non-enzymatic browning (Fig 4.44). The aroma score dropped from 7.2 ± 0.25 to 5.7 ± 0.15, likely due to the volatilization and oxidation of aromatic compounds. The consistency/texture score diminished from 7.7± 0.33 to 6.3 ± 0.21, possibly because of moisture migration and textural changes in the product matrix. Overall acceptability for RJB decreased from 7.8 ± 0.35 to 5.8 ± 0.20, reflecting the cumulative effect of these sensory changes. In the case of RJP, the colour score decreased from 7± 0.15 to 5.8 ± 0.18, which might be due to similar reasons

of pigment degradation. The aroma score reduction from 7 ± 0.25 to 5.92 ± 0.21 can be attributed to the loss of volatile flavor compounds over time. The consistency/texture score fell from 7.1 ± 0.18 to 5.72 ± 0.24, likely due to the breakdown of cell structure and changes in the pulp's physical properties. Consequently, the overall acceptability of RJP decreased from 7 ± 0.32 to 5.6 ± 0.20 (Fig 4.45), demonstrating the impact of these changes on the product's sensory profile. Overall, while the initial sensory qualities of retort pouch processed RJB and RJP were high, the natural decline over storage highlights areas for further research and optimization to enhance shelf life and maintain sensory attributes.

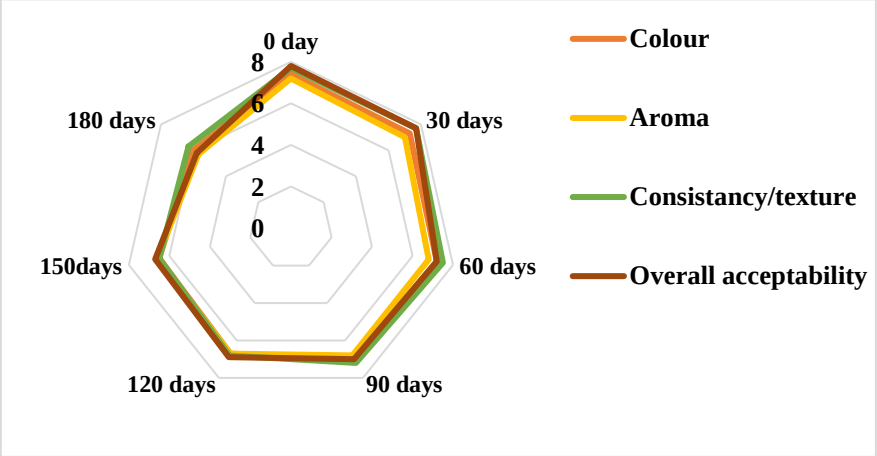


Fig 4.44 Effect of storage on sensory characteristics of retort pouch pasteurised RJB

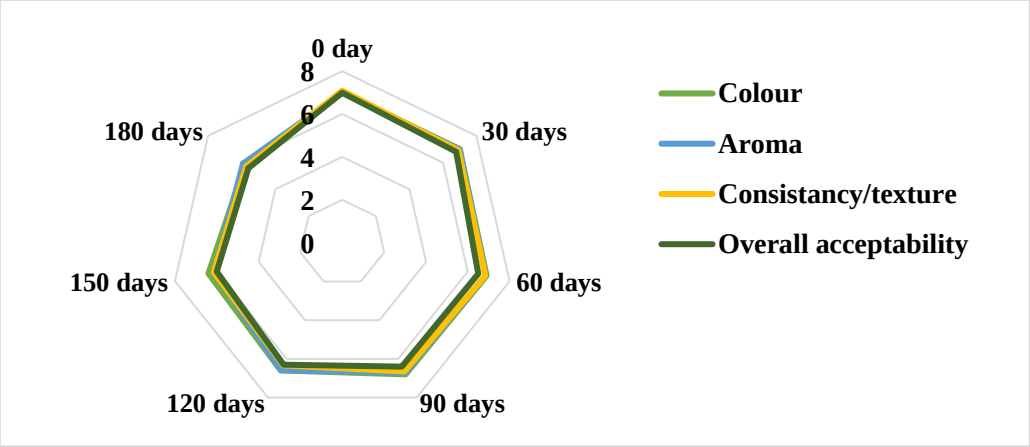


Fig 4.45 Effect of storage on sensory characteristics of retort pouch pasteurised RJP

The study on the sensory evaluation of retort pouch sterilised RJB and RJP during storage showed encouraging initial results, highlighting the effectiveness of the retort sterilisation process in maintaining high sensory quality. On day 1, RJB exhibited high overall acceptability with a score of 7.15 ± 0.19, supported by scores of 7 ± 0.15 for colour, 7.2 ± 0.21 for aroma, and 6.8 ± 0.31 for consistency/texture (Fig 4.46). Similarly, RJP demonstrated strong initial performance with an overall acceptability score of 6.8 ± 0.12, and scores of 6.8±0.24 for colour, 6.5 ± 0.23 for aroma, and 6.5 ± 0.29 for consistency/texture (Fig 4.47).

However, the data revealed a gradual decline in sensory attributes over the storage period. For RJB, the colour score decreased from 7 ± 0.34 to 6.12 ± 0.28 over 180 days, likely due to pigment degradation and non-enzymatic browning. The aroma score fell from 7.2 ± 0.34 to 5.8 ± 0.27, possibly caused by the volatilization and oxidation of aromatic compounds. The consistency/texture score declined from 6.8 ± 0.17 to 5.79 ± 0.26, which may be attributed to moisture loss and textural changes in the product matrix. Consequently, the overall acceptability of RJB decreased from 7.15 ± 0.04 to 5.8 ± 0.26, reflecting these cumulative changes.

In the case of RJP, the colour score dropped from 6.8 ± 0.24 to 5.91 ±0.21, which could be due to similar pigment degradation. The aroma score decreased from 6.5 ± 0.30 to 5.32 ± 0.19, possibly due to the loss of volatile flavor compounds over time. The consistency/texture score reduced from 6.5 ± 0.17 to 5.7 ± 0.06, likely because of the breakdown of cell structure and changes in the pulp's physical properties. As a result, the overall acceptability of RJP declined from 6.8 ± 0.18 to 5.71 ± 0.20 over 180 days, illustrating the impact of these changes on the product's sensory profile. These findings are consistent with previous studies on the storage stability of jackfruit powder, which reported a significant decrease in the intensities of fruity odour, taste, and an increase in lumpiness over time, particularly at higher temperatures and humidity levels. The gradual decline in sensory attributes observed in the current study illustrates the challenges of maintaining quality in retort pouch sterilised jackfruit products during storage (Lakshmana *et al*, 2013)

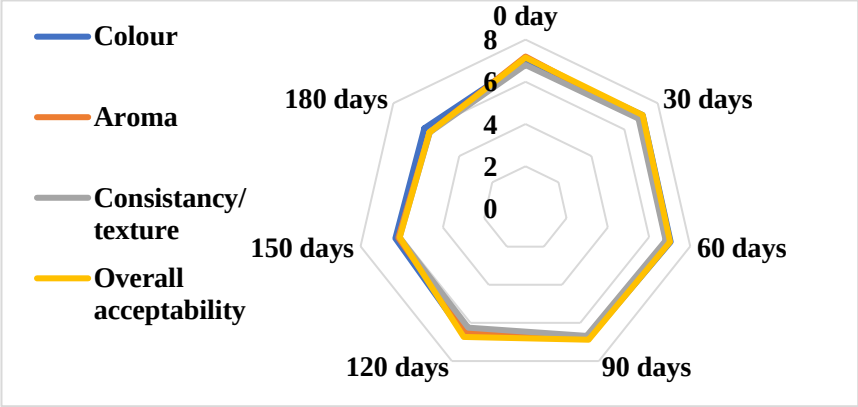


Fig.4.46 Effect of storage on sensory characteristics of retort pouch sterilised RJB

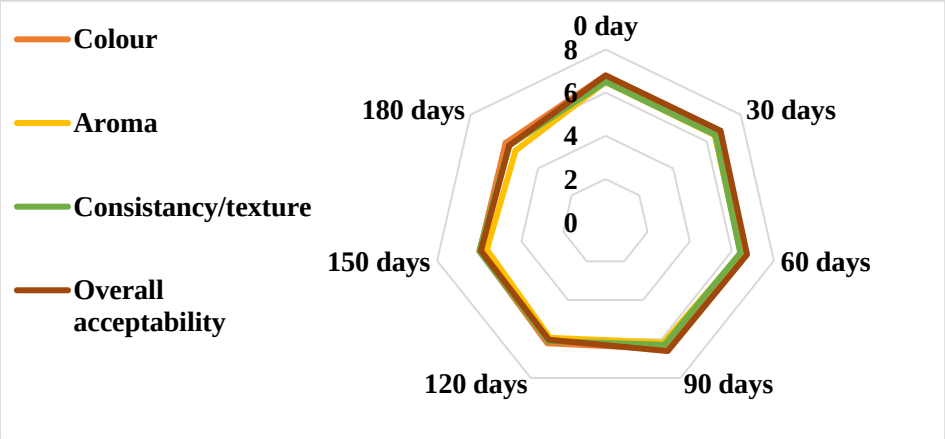


Fig.4.47 Effect of storage on sensory characteristics of retort sterilised RJP

The storage study demonstrated that the retort pouch-processed RJB and RJP maintained their quality and safety for up to 180 days. Throughout the storage period, there were no significant changes in sensory attributes, microbial safety, or physicochemical properties, confirming the effectiveness of retort processing in preserving these products. These findings highlight the potential of retort pouch packaging as a viable method for extending the shelf life of RJB and RJP, ensuring their stability for long-term storage and commercial distribution.

EXPERIMENT II:

4.4 STANDARDISATION OF HPP PARAMETERS FOR RJB AND RJP

This chapter focuses on the physico-chemical properties and economic aspects of high-pressure processed RJBs and RJP. The investigation explores the effects of applying various pressures at different holding times on these properties explained below. Table 4.8 below is the physico-chemical properties of ripe jackfruit samples prior to processing

Table. 4.8 Proximate composition of fresh ripe jackfruit prior to HPP

Sl. No.	Parameter		RJB	RJP
1	pH		5.10 ± 0.23	5.00 ± 0.18
2	TSS (ºBrix)		22.60 ± 0.59	23.00 ± 1.05
3	TA%		0.50 ± 0.013	0.51 ± 0.018
4	TPC (mg GAE/g)		61.63 ±2.82	64.78 ± 3.06
5	TFC (mg RE/g)		34.89 ±1.69	17.06 ± 0.61
6	Ascorbic acid (mg/100 g)		13.68 ± 0.64	7.84 ± 0.38
7	Colour	L^*	33.06 ± 1.61	48.56 ± 1.75
		a^*	8.01 ± 0.367	8.13 ± 0.37
		b^*	51.83 ± 1.79	56.65 ±1.49
8	Total Sugar (%)		25.49 ± 1.11	22.62 ± 0.59

Where RJB: Ripe jackfruit bulb, RJP:Ripe jackfruit pulp; Data shown are the mean±SD of three treatment repetition

4.4.1 Effect of HPP on quality characteristics of ripe jackfruit

4.4.1.1 Effect of HPP on pH, TA, and TSS of ripe jackfruit

Assessing pH and TA is crucial, as these factors can influence the microbial growth and stability of food products. Consequently, the pH and TA of ripe jackfruit samples (RJB and RJP) were examined before and after processing. The initial pH of the fresh RJB and RJP was 5.10 ± 0.23 and 5.00 ± 0.18, respectively. Following high-pressure treatment, these values varied from 4.80 ± 0.22 to 5.20 ± 0.03 in RJP and 4.6 ± 0.12 to 4.9 ± 0.13 in RJB. For fresh RJP and RJBs, the initial TA was 0.51 ± 0.03% and 0.50 ±

0.21%, respectively, with post-processing values ranging from 0.49 ± 0.02% to 0.69 ± 0.02% for the RJP and 0.50 ± 0.02% to 0.65 ± 0.02% for the RJB. A significant decline in pH and a rise in TA were noted in both RJB and RJP as the pressure and holding time increased. However, these trends were determined to be statistically insignificant ($p > 0.05$). This aligns with the findings from numerous studies, which consistently reported minimal to minor variations in pH and TA following the pressure treatment of juices and purees. A study by Bialkowski and Kaczmarek (2019) on passion fruit purée found that HPP (600 MPa/5 min) had little effect on pH and TA compared to control samples. This underscores the non-damaging effect of high pressure on the covalent bonds present in ripe jackfruit samples (Pacheco and Kauffman, 2020).

The elevated pressure has previously been confirmed to boost the ionic dissociation constant of water and weak acids in food, as noted by Zhang *et al*., 2021. This outcome leads to a higher concentration of freely available H+ ions within the food matrix. From the Table 4.9, it is evident that the maximum pH reduction was reported at elevated processing conditions of 600 MPa, 20 min and the TA increased by a maximum of 0.19 units at 600 MPa for a 20 minut treatment for high pressure processed RJB. Similarly, RJP processed under lower pressure and holding time exhibited the minimum variation in pH and titrable acidity values in processed RJP.

The TSS content in the fresh RJB was determined to be 22.6 ± 0.59 ˚Brix, while for the RJP, it measured 23 ± 1.05 ˚Brix. Following HPP, there was a variation in TSS, ranging from 21.04 ± 1.04 to 22.6 ± 0.80 ˚Brix for the RJB and 22.75 ± 0.82 to 23.10 ± 0.83 ˚Brix for the RJP. TSS, indicative of the approximate soluble sugar content in a solution, exhibited a marginal decrease in RJBs after HPP; nevertheless, this decrease was not statistically significant ($p > 0.05$). The slight decrease in the TSS value observed after HPP may be attributed to the loss of sugars seeping out from the RJBs under elevated pressures. A notable reduction in TSS amounting to 21.04 ± 1.04 ˚Brix and 22.75 ± 0.82 ˚Brix was observed under the treatment conditions of 600 MPa for 20 min, respectively for RJB and RJP. In contrast, a stable TSS value of 22.6 ± 0.81˚Brix was maintained in RJB when subjected to 300 MPa for 5 min. The TSS content of RJP subjected to HPP remained nearly constant (23.10 ± 0.83 ˚Brix) at lower pressure. This stability can be attributed to the absence of anticipated bond breaking initiated by the

applied pressure, indicating the resilience of the soluble components in the RJP to structural changes unde
(Jayachandran *et al*., 2015).

Table 4.9 Effect of HPP on pH, TA, and TSS of ripe jackfruit

Treatment		RJB			RJP	
Pressure (MPa)	**Holding time (min)**	**pH**	**TSS (˚B)**	**TA (%)**	**pH**	**TSS ˚(B)**
300	5	4.9±0.18	22.6±0.81	0.53±0.02	5.2±0.03	23.1±0.83
600	5	4.8±0.13	22.4±0.59	0.57±0.02	4.9±0.23	23.2±0.61
300	20	4.8±0.22	22.5±0.12	0.56±0.03	4.9±0.12	22.9±0.83
600	20	4.6±0.03	21.0±1.04	0.69±0.02	4.8±0.13	22.75±0.82
238	12.5	4.9±0.22	22.6±0.80	0.54±0.02	5.0±0.06	23.00±0.61
662	12.5	4.8±0.17	22.1±0.60	0.59±0.02	4.9±0.18	23.1±1.01
450	2	4.9±0.13	22.5±0.25	0.57±0.02	5.1±0.14	23.1±1.06
450	23	4.7±0.05	21.9±0.80	0.6±0.007	4.8±0.21	22.95±1.05
450	12.5	4.8±0.17	22.3±0.60	0.57±0.02	4.9±0.23	23.0±0.83
450	12.5	4.6±0.12	22.5±0.92	0.55±0.03	4.8±0.22	22.8±0.60
450	12.5	4.8±0.21	21.1±1.02	0.57±0.02	4.8±0.17	23.7±1.03
450	12.5	4.9±0.22	22.3±1.01	0.43±0.03	5.1±0.14	23.15±0.81
450	12.5	4.6±0.21	22.0±0.80	0.56±.004	5.2±0.23	22.9±1.05

Where TSS-Total soluble solids, TA-Titrable acidity; Data shown are the mean±SD of three trea

4.4.1.2 Effect of HPP on colour characteristics of ripe jackfruit

The untreated ripe jackfruit samples demonstrated colour characteristics with L*=35.06 ± 1.60, a*=8.01 ± 0.29, b*=51.83 ± 1.37 for the RJB, and L*=48.56 ± 0.56, a*=8.13 ± 0.29, b*=56.65 ± 1.49 for the RJP. Following processing, the general trend in the colour of ripe jackfruit indicated an elevation in lightness (L* value) from 34.09 ± 1.51 to 42.64 ± 1.86 and 49.54 ± 2.27 to 51.48 ± 1.85 respectively for RJB and RJP (Fig 4.48 a&b). The study's results reveal that the lightness of ripe jackfruit samples experienced a notable change at the minimal applied pressure, and this modification was statistically significant ($p < 0.05$). This effect on lightness was observed consistently across various compression pressures. The results emphasize the sensitivity of the lightness parameter to the applied pressure, irrespective of the specific compression pressure employed. In this study, it was observed that ripe jackfruit samples treated with the lowest pressure (300 MPa) exhibited the darkest colour, while those treated with the highest pressure (600 MPa) displayed the lightest shade.

The pressure and holding time also had significant effect on L* value of HPP processed RJB and RJP. The effect of pressure on L* was found to be significantly higher compared to holding time. The polynomial model was found to fit well in describing the effect of variables on the L* value showing the adequacy of the model (R^2_{RJB} = 0.98%, R^2_{RJP}= 0.83% given in Table C3 & C4). The regression model obtained can be written as follows for L* value.

$$L_{RJB}^{*} = 35.81 + 2.14\,P + 0.64\,Ht + 0.26\,P\,Ht + 1.01\,A^2 + 0.68\,Ht^2 \quad \ldots (4.52)$$

$$L_{RJP}^{*} = 50.42 + 0.50\,P + 0.37\,Ht - 0.38\,P\,Ht + 0.20\,P^2 + 0.28\,Ht^2 \quad \ldots (4.53)$$

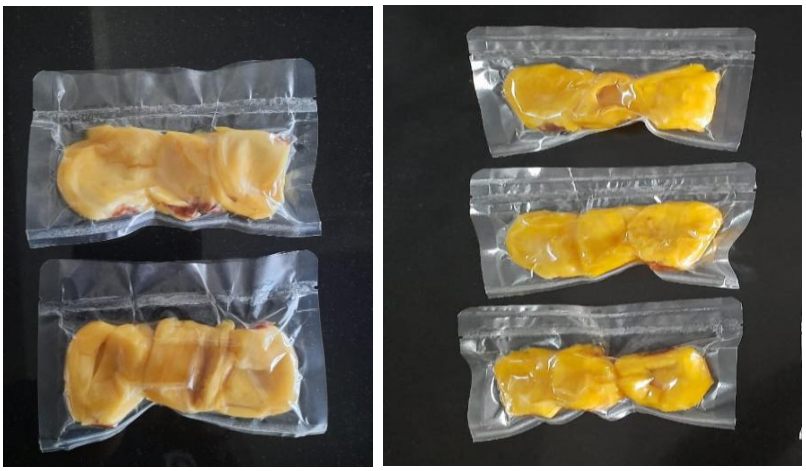
Where, L_{RJB} *: L* of RJB; L_{RJP} *: L* of RJP; P: Pressure in MPa and Ht: Holding time in min

A minor rise in L* (lightness) values was detected in the treated ripe jackfruit samples, suggesting the potential expulsion of air from RJB tissue during pressurization. This phenomenon contributed to the lightening and increased opacity of the samples (Saranya *et al*., 2024). The results, consistent with Kaushik *et al*. (2014), reflected an increase in lightness in pressurized mango pulp processed at 100 to 600 MPa for holding times of 1 to 20 min. The lightness value L* for the HP-treated jackfruit

shreds increased with pressure and holding time, aligning with Ng *et al*. (2020) hypothesis that the decline in L* was possibly due to micelles breaking up into small fragments under pressure. Oey *et al*. (2008) suggested that alterations in L* values in pressurized fruit products could be linked to the creation of a jelly-like translucent structure. This structure, in turn, influences the transparency or opacity of the product.

In comparison to the L* value, other chromatic parameters like a* and b* values exhibited a decrease following HPP processing. The a* value for jackfruit samples subjected to HPP treatment varied from 7.93 ± 0.02 to 8.08 ± 0.02 in RJB (Table 4.10) and 8.06 ± 0.21 to 9.32 ± 0.25 in RJP and were non significant ($p>0.05$) also lower than that of the untreated control sample (Table 4.10). A similar declining pattern in a* values was also noted by Varela-Santos *et al*. (2012) in pomegranate juice processed under high pressure. The negative a* value indicated an incomplete enzyme inactivation post-processing, contributing to the loss of red colour.

The yellow colour in ripe jackfruit is primarily attributed to the presence of carotenoid pigments including compounds like beta-carotene and lutein. The stability of the yellow colour, as indicated by the b* value, remained stable at higher pressures and holding times. The b* value for the fresh untreated RJB sample was 51.83 ± 0.37, while for the treated samples, it varied from 51.26 ± 0.93 to 51.77 ± 0.58. While the b* value for the untreated RJP sample was 56.65 ± 1.49, the treated samples exhibited a range from 55.12 ±1.46 to 56.62 ± 2.04. Referring to Figure 2, the treatments conducted at 600 MPa for 20 min showcased the maximum yellowness for both treated RJP and RJB. These results are consistent with earlier investigations by Oey *et al*. (2008) and Andrés *et al*. (2016), indicating that the carotenoid pigments accountable for the yellow hue in jackfruit remain stable under high-pressure conditions and are preserved. According to Stinco *et al*. (2019), in the treatment of cloudy carrot juice, the application of the highest pressure not only led to reduced degradation of carotenoids but also facilitated a more effective extraction of carotenoids compared to other treatments assessed. These results resonate with the present study, underscoring the resilience and preservation of carotenoid pigments in ripe jackfruit when subjected to high-pressure conditions. Plates 4.9 and 4.10 given below is the change in appearance of the jackfruit samples



(a) (b)

Plate 4.9 RJB samples (a) before HPP and (b) after HPP

(a) (b)

Plate 4.10 RJP samples (a)before HPP and (b)after HPP

4.4.1.3 Effect of HPP on ΔE, BI and YI of ripe jackfruit

The HPP-treated ripe RJB exhibited ΔE values ranging from 1.12 ± 0.01 to 9.58 ± 0.20 (Fig 4.49c), while the range for the RJP was 1.54 ± 0.05 to 2.94 ± 0.11 CIELAB units. This implies that the colour disparities in the treated RJB were observed within a broader range compared to the RJP, as indicated by the ΔE values in the CIELAB colour space. These variations suggest that HPP treatments induce colour changes in ripe jackfruit, which are discernible by untrained observers. Among the treatments, the RJP displayed the least colour deviation, registering at 1.54 ± 0.05, following exposure to HPP at 300 MPa for 5 min, compared to the fresh sample. Similarly, for the RJB, the colour deviation was 1.12 ± 0.01 at 300 MPa for 5 min.

Jayachandran *et al*. (2015) delineated ΔE values across various ranges to signify the degree of colour disparity in processed samples concerning the fresh untreated sample. According to their study, the ΔE values of treated RJP fell within the range of 1.5–3.0, indicating a distinct difference, while high treatment combinations (600 MPa, 20 min) for the HPP treated RJB showed a great difference. Stinco *et al*. (2019) also documented the most substantial colour difference observed at 600 MPa in HPP treated cloudy carrot juice.

$$\Delta E_{RJB} = 2.78 + 2.97\,P + 0.87\,Ht + 0.28\,P\,Ht + 1.51\,P^2 + 0.67\,Ht^2 \quad \ldots (4.54)$$

$$\Delta E_{RJP} = 2.17 + 0.36\,P + 0.29\,Ht - 0.27\,P\,Ht + 0.13\,P^2 + 0.19\,Ht^2 \quad \ldots (4.55)$$

Where, ΔE_{RJB} and ΔE_{RJP} represents the total colour deviation of RJB and RJP respectively, P: Pressure in MPa and Ht: Holding time in min. The R^2 values for ΔE_{RJB} and ΔE_{RJP} is 0.98 and 0.75 respectively (Table C4 & C5).

The BI for fresh RJB was reported as 308.16±1.69, contrasting with 150.34 ± 1.88 for fresh RJP. Post-processing, the BI ranged from 160.49 ± 1.62 to 268.05 ± 2.47 for RJB (Fig 4.49a) and 137.01 ± 1.67 to 143.56 ± 2.17 for RJP. Despite varying pressure and treatment times during HPP, there were no significant ($p > 0.05$) changes in BI values for RJP compared to the control sample. This aligns with findings from Zou *et al*. (2016), they reported that HPP treatment did not induce significant changes in the BI value of mulberry juice. During HPP, there were notable changes in the BI values observed in RJBs, with statistical significance ($p < 0.05$). The pronounced alterations in L*, a*, and b* values in the RJBs, compared to the RJP, likely contribute to the observed significant variations in BI values. BI exhibited a decline across all alternative pressure treatments, correlating with an escalation in both pressure magnitude and the duration of holding time. Maximum reduction in BI was noted at 600 MPa, 20 min. in HPP processed RJB. This observation underscores a consistent inverse relationship between BI values and the intensified pressure conditions, suggesting a notable impact on the biological response with increased pressure levels and prolonged exposure duration. The observed decrease in BI values across various pressure treatments is likely a result of pressure-induced partial enzyme inactivation. The literature has documented that pressure can diminish the rate of enzymatic reactions by causing alterations in the native structure of enzymes. This can occur through either

protein denaturation or by inducing changes in the spatial arrangement of the active site. Therefore, the consistent decline in BI values as pressure levels and holding times increase may be attributed to the pressure-induced modifications in enzyme activity (Ludikhuyze *et al.*, 2003). An R^2 value of 0.99 indicates strong fitness for the polynomial model used to describe the impact of variables on BI. The influence of pressure and holding time on BI can be visually represented through the 3D surface plots depicted in Figure 4.49a. The expression for the regression model concerning the BI value of RJB processed under high pressure is as follows.

$$BI_{RJB} = 231.85 - 36.24\ P - 11.57\ Ht + 3.37\ P\ Ht - 12.89\ P^2 - 8.57\ Ht^2 \quad \ldots (4.56)$$

Where, RJB: RJB; RJP: RJP; P: Pressure in MPa and Ht: Holding time in min.

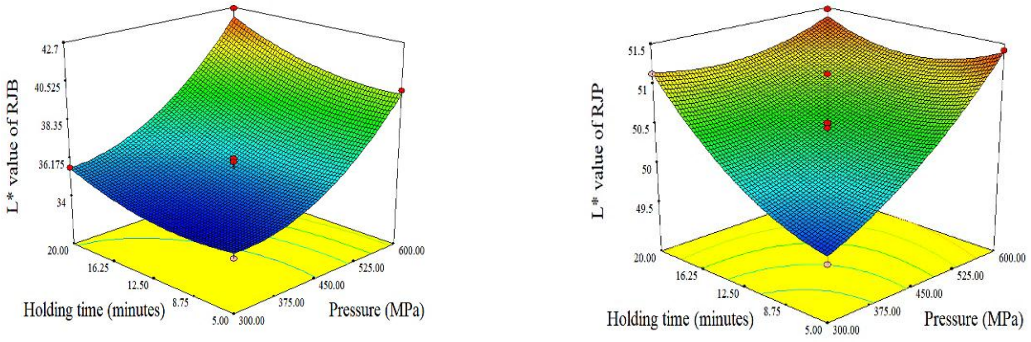
The YI for RJB after pressurization ranged from 173.44 ±1.56 to 215.58 ± 2.61 (Fig 4.48b), differing from the untreated samples at 223.96 ± 2.67. Similarly, in HP-processed RJP, it ranged from 156.15 ± 2.12 to 161.38 ± 2.81, contrasting with the fresh control having 166.66 ± 2.40 YI. Pressure and holding time had a significant effect ($p < 0.05$) on the YI of the RJB. However, a non-significant effect ($p>0.05$) on YI was observed in RJP. In the case of the YI value of HPP processed RJB, the pressure and holding time were determined as significant model terms. Equation (4.55) describes the relationship between the independent variables and BI of HPP processed RJB.

$$YI_{RJB} = 205.54 - 14.67\ P - 4.38\ Ht - 0.54\ PHt - 6.79P^2 - 3.35\ Ht^2 \quad \ldots (4.57)$$

Where, P: Pressure in MPa and Ht: Holding time in min. The R^2 value for YI_{RJB} noted as 0.98 and for BI_{RJB} it is 0.97 (Table C20 & C19).

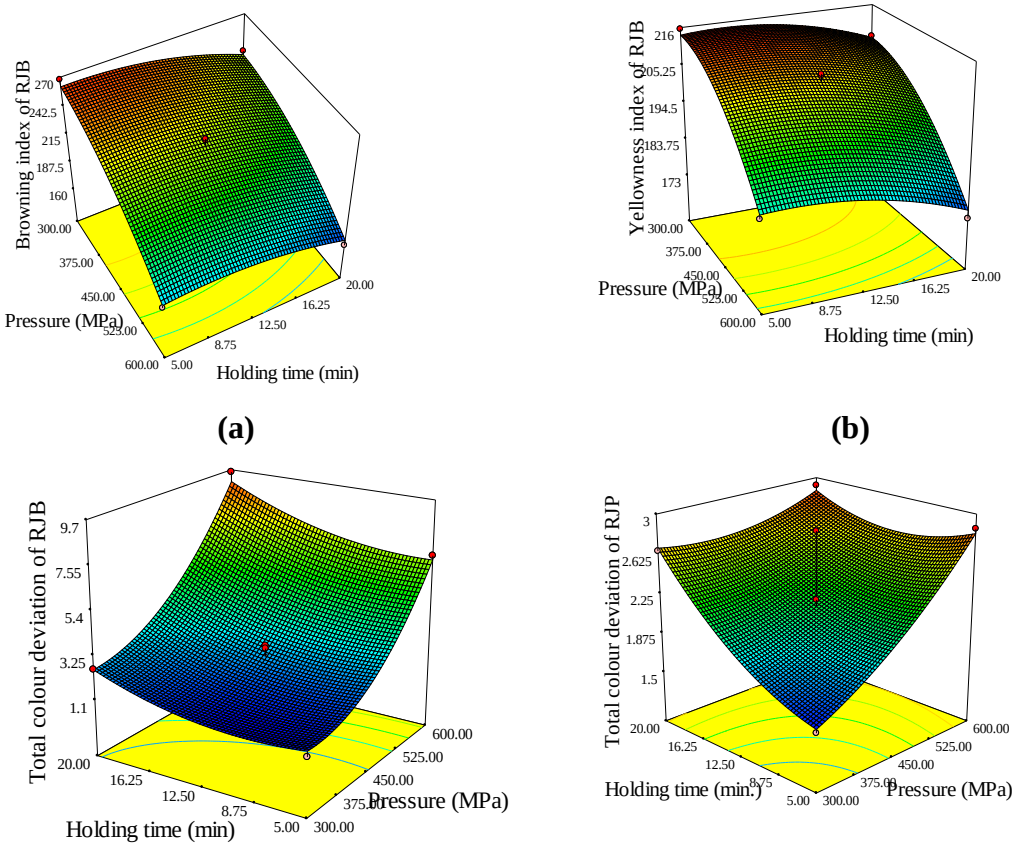
In HPP ripe jackfruit samples, YI was noticed to be decreasing with an increase in pressure. A maximum decrease of about 6.31% in YI at 300 MPa for 20 min treatment was obtained for RJP and maximum carotenoid retention was observed at lower treatment conditions of 300 MPa, 5 min. The elevation in L* may have contributed to the reduction in YI, while the samples' opacity increased post-pressurization due to air release, leading to a decline in YI at elevated pressures (Kaushik *et al.*, 2014). The research emphasized that carotenoids, known for their resilience to pressure, did not contribute to the negative effects observed in YI under increased pressure conditions.

This corresponds with the findings of González-Cebrino *et al*. (2012), who reported similar results in the HPP of red flesh and peel plum. Kaushik *et al*. (2014) also observed an 8% maximum reduction in YI during the HPP of mango pulp at 100 MPa for 20 min.



(a) **(b)**

Fig. 4.48 Effect of HPP on L * value of RJB and RJP respectively



(a) **(b)**

(c) **(d)**

Fig. 4.49 Effect of HPP on BI, YI, ΔE of RJB and ΔE of RJP respectively

Table. 4.10 Colour characteristics of HPP ripe jackfruit samples

Treatments		RJB		RJP		
Pressure (MPa)	Holding time (min)	a*	b*	a*	b*	YI
300	5	8.02±0.02	51.45±0.98	8.88±0.42	55.62±2.01	160.39±1.85
600	5	7.95±0.01	51.73±0.99	8.18±0.39	56.36±1.50	156.58±5.64
300	20	8.03±0.02	51.55±0.78	8.29±0.30	55.88±0.65	156.13±4.13
600	20	7.93±0.02	51.77±0.58	8.06±0.21	56.62±2.04	157.12±6.85
238	12.5	8.02±0.03	51.47±0.94	8.75±0.40	55.63±1.47	158.34±7.26
662	12.5	7.95±0.03	51.75±0.75	8.15±0.05	56.48±2.46	156.88±7.18
450	2	8.02±0.02	51.57±0.99	8.83±0.40	56.03±2.57	158.47±5.71
450	23	7.94±0.01	51.72±0.78	8.55±0.31	56.25±2.58	156.16±4.13
450	12.5	7.96±0.02	51.57±0.57	8.65±0.23	56.34±2.03	158.75±6.92
450	12.5	7.97±0.02	51.55±0.78	8.75±0.10	55.12±1.46	157.71±5.46
450	12.5	7.95±0.02	51.26±0.93	8.9±0.32	56.54±2.46	161.39±7.39
450	12.5	8.08±0.02	51.77±0.77	9.32±0.25	56.28±1.95	157.25±5.67
450	12.5	7.94±0.01	51.41±0.58	8.42±0.37	55.46±2.54	157.05±4.15

Where ΔE-Colour deviation, YI-yellowness index, and BI- browning index, RJB-Ripe jackfruit bulb, RJP-Ri*
Data shown are the mean±SD of three treatment repetition

4.4.1.4 Effect of HPP on AA of ripe jackfruit

AA is a remarkably sensitive compound, and its stability is notably influenced by processing methods and environmental factors (Tewari *et al*., 2017). A significant ($p<0.05$) rise in the AA content was noted in ripe jackfruit samples subjected to HPP. When compared to the control sample (fresh RJB-13.68 ± 0.62 mg/100 g), the AA content in the treated RJB samples (ranging from 13.94 ± 0.63 to 16.82±0.82 mg/100 g) showed a maximum elevation of 23% in AA Notably, the highest content was observed at 600 MPa, 20-min holding time (Fig. 4.50).

It was noted that AA is susceptible to factors like heat, light, and oxygen exposure, commonly encountered in the pulping process during the conversion of fruits into pulp (Tewari *et al*., 2017). The statement indicated that mechanical processing could decrease AA content, leading to reduced AA levels in the RJP compared to RJBs (Arampath and Dekkera., 2019). In the case of HPP processed RJP, the AA content ranged from 7.85±0.35 to 9.91 ± 0.46 mg/100 g. The reported findings highlighted a similar trend to that observed in HPP treated RJBs, with a 17% increase in the processed RJP compared to the control sample value of 7.84 ± 0.37 mg/100 g. High retention of AA was noted at 300 MPa, 5 min and higher AA was observed at 600 MPa, 20 min condition. The quadratic polynomial model was developed for AA concerning process parameters, demonstrates the interaction between pressure and holding time as depicted in Equation (2). This interaction is also evident in the response surface plot, indicating that pressure had the most significant impact on AA extraction compared to holding time (Fig. 4.49a and b).

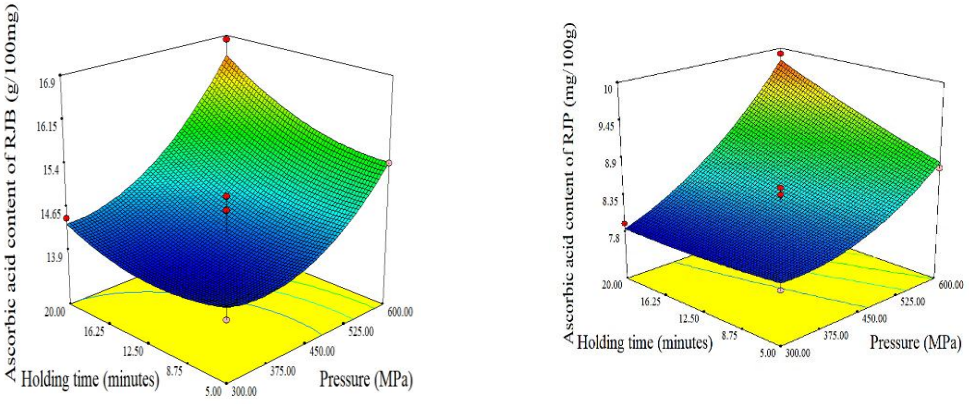
According to Landl *et al*. (2010), HPP generally has minimal effects on the AA content of fruits and vegetables, but it can be influenced by enzymatic reactions and chemical changes during pressurization. Briones-Labarca *et al*. (2013) noted that HPP might act as a facilitator for enhanced extraction of bioactive compounds from fruits. Kaushik *et al*. (2014) proposed that the increase in AA content in ripe jackfruit samples subjected to HPP might be attributed to cytoplasmic rupture and the subsequent release of contents into the extracellular space during compression. The regression model obtained can be written as follows. The R^2 values for AA_{RJB} and AA_{RJP} is 0.91 and 0.96

respectively. The ANOVA table for AA after HPP is given in Table C7 & C12 in Appendix C)

AA_{RJB} (mg/100 g) =14.28+0.87 P+0.33 Ht +0.22 P Ht +0.55 P^2+0.28 Ht^2 …(4.58)

AA_{RJP} (mg/100 g) =8.31+0.71 P+0.21 Ht +0.27 P Ht +0.27P^2+0.039 Ht^2 …(4.59)

Where, AA_{RJB}: AA of RJB; AA_{RJP}:AA of RJP; P: Pressure in MPa and Ht: Holding time in min



(a) **(b)**

Fig.4.50 Effect of HPP on AA of ripe jackfruit samples

4.4.1.5 Effect of HPP on TPC and TFC of ripe jackfruit

In previous studies, HPP impacted macromolecular structures in fruit and vegetable matrices (Gopal *et al*.,2017, Bansal *et al*., 2019, Nawawi *et al.*, 2023). The pressure difference generated by HPP across cell membranes enhances cell permeability, causing the breakdown of intracellular juice vesicles and releasing matrix-bound polyphenolic compounds, encompassing both flavonoids and non-flavanoids (Grunovaite *et al*., 2016).

This study revealed that the TPC in ripe jackfruit samples after pressure treatment ranged from 64.80 ± 2.96 to 66.02 ± 1.74 mg GAE/g for the RJB (Fig 4.51a) and 61.66 ± 1.63 to 70.12 ± 3.25 mg GAE/g for the RJP (Fig 4.51b). The results indicated a notable rise in TPC when the pressure was concurrently increased from 300 to 600 MPa, in comparison to the control samples (64.78 ± 2.96 mg GAE/g for both

RJP and RJB). The most significant ($p<0.05$) improvement, reflecting a 15.2% increase in TPC, occurred at 600 MPa for 20 min for the RJB, while the RJP experienced a 2% increase under the same conditions. Pressure had a significant effect on TPC of RJB and RJP. A non-significant lack of fit of the model suggests that the model is adequate for describing the relationship between the independent and dependent variables. The relationship between the dependent variable and the independent variables in terms of coded factors is given in Eqn (4.60 to 4.63). This improvement is credited to the increased extractability of specific antioxidant compounds at higher pressure levels, leading to the disruption of cell walls. According to Nayak *et al*. (2017), both elephant apple juice and strawberry puree exhibited comparable results when subjected to pressurization at 600 MPa, showing a rise in TPC of 9.8%. In a study by Fernández-Jalao *et al*. (2019) on the effects of HPP on flavonoids in Golden Delicious apples from Spain and Italy, it was found that treating Spain-apples at 400 MPa resulted in a notable increase of 22–35% in phenolics, specifically Q-3-galactoside, Q-3-glucoside, Q-3-arabinoside, Q-3-xyloside, and Q-3-Rhamnoside. This aligns with the general trend observed in various fruits and purees under high-pressure conditions

The extraction of flavonoids in all treatments exhibited a comparable pattern to the extraction of total phenols, indicating an elevation with increasing pressure levels (Fig. 4.52). In comparison to the control value of 33.89 ± mg RE/g, the TFC of HPP processed RJB rose from 35.12 ± 1.23 to 43.68 ± 1.57 mg RE/g. The maximum amounts of flavonoids were reported as 43.68 ± 1.57 mg RE/g at a higher pressure of 600 MPa for 20 min (Fig 4.52a). Concerning the RJP, the TFC ranged from 17.13 ± 0.45 to 22.85 ± 0.99 mg RE/g (Fig 4.52b), with the control sample showing a lower value of 17.06 ± 0.59 mg RE/g. Additionally, the highest extraction yields for flavonoids, specifically 25% for HP processed RJB and 22% for RJP, were noted at 600 MPa for 20 min. This aligns with the earlier observation by Abid *et al*. (2014) in apple juice subjected to 450 MPa treatment.

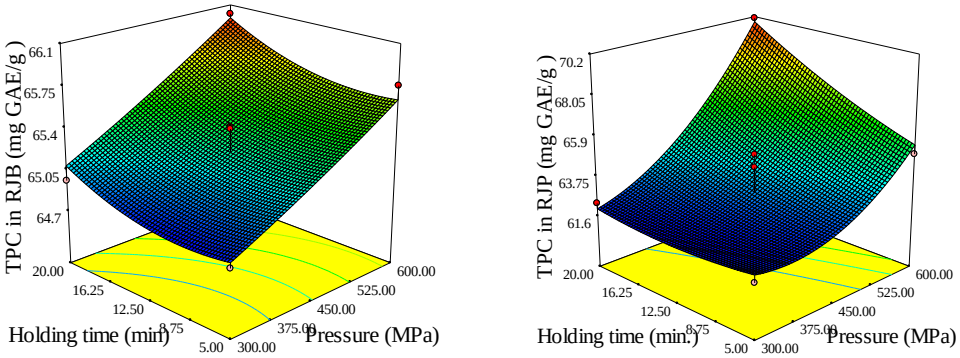
The statistical analysis indicated that both pressure and holding time, as well as their interactions, had a positive and significant effect on the HPP of ripe jackfruit samples. The regression equation derived from the model in terms of coded factors is given belowin Table 4.11 and ANOVA table is given in Appendix C. Flavanols

exhibited a comparable increase in multiple studies, such as in a soymilk beverage treated at 400 MPa (Rodríguez-Roque *et al*., 2016) and orange juice subjected to 550 MPa (Vieira *et al*., 2018). This underscores the importance of a well-balanced combination of high pressure and extraction time to improve extraction yields, consistent with prior research indicating the efficacy of HPP treatment in extracting phenols and flavonoids.

Table 4.11 Regression equation in terms of coded factors

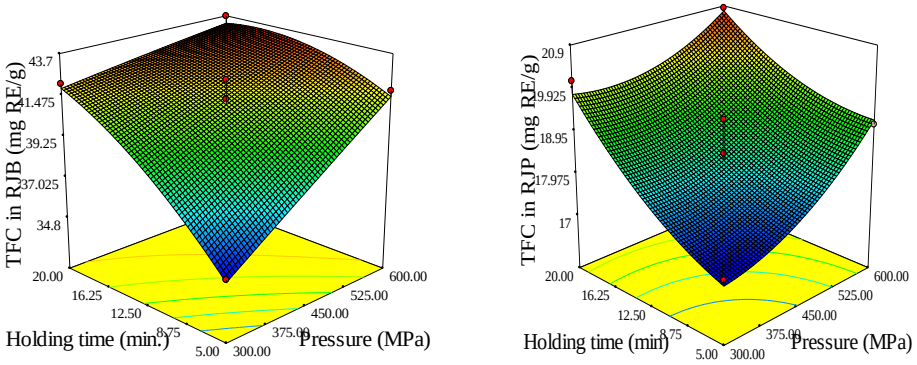
TPC_{RJB}= 65.24+0.42* P+0.15* Ht+0.025 *P* Ht +0.027* P^2+0.13* Ht^2	... (4.60)
TPC_{RJP}= 63.14+2.84* P+1.09* Ht +1.13* P * Ht +1.38* P^2+0.33* Ht^2	… (4.61)
TFC_{RJP}= 18.40+0.80* P+1.09* Ht -0.31* P * Ht +0.44* P^2+0.37* Ht^2	… (4.62)
TFC_{RJB}= 41.23+1.96* P+2.18* Ht -1.26* P * Ht -0.038* P^2-0.80* Ht^2	… (4.63)

Where TPC-Total phenolic compounds, TFC-Total flavonoid content, RJB: Ripe jackfruit bulb; RJP: Ripe jackfruit pulp; P: Pressure in MPa and Ht: Holding time in min



(a) **(b)**

Fig. 4.51 Effect of HPP on TPC of ripe jackfruit samples



(a) **(b)**

Fig. 4.52 Effect of HPP on TFC of ripe jackfruit samples

4.4.1.6 Effect of HPP on Total sugar of ripe jackfruit

Sugars play a crucial role as a sensory indicator influencing consumer perception (Liu *et al*., 2013). Typically, it is evaluated through total sugar, and reducing sugar levels. The assessment of total sugar in ripe jackfruit samples resulted in a range of 25.45 ± 0.91 to 25.50± 0.93 g/100 g for RJB (Table 4.12), while the control sample exhibited a total sugar content of 25.49 ± 0.85 g/100 g. The research indicates that there was a negligible variance in total sugar content before and after processing, and this difference was not statistically significant ($p>0.05$). Comparable outcomes were observed in the HPP processed RJP, where the total sugar content remained unchanged even post-processing. The initial total sugar content of the fresh RJP was 22.62 ± 0.62 g/100 g, and post-processing, it ranged from 22.62 ± 0.26 to 22.68 ± 0.99 g/100 g. This suggests that the pressure and holding time had no impact on the total sugars of ripe jackfruit samples. Similarly, Liu *et al*. (2016) found a non-significant effect on total sugars in both blanched and unblanched mango RJP after HP processing. Butz *et al*. (2002) reported that there were no significant differences in the sucrose, glucose, and fructose levels in HPP processed fresh juices from tomatoes, oranges, peaches, carrots, apples, and strawberries.

4.4.1.7 Effect of HPP on DPPH radical scavenging activity of ripe jackfruit

The control RJB and RJP were examined for antioxidant capacity through DPPH radical scavenging activity, yielding values of 88.55 ± 4.05 and 87.54 ± 3.1% DPPH radical scavenging activity, respectively. After processing, the DPPH radical scavenging activity in RJB ranged from 88.63 ± 2.34 to 91 ±1.04% (Fig 4.53a), while in RJP, it varied from 87.56 ± 3.15 to 89.92 ± 1.05% (Fig 4.53b). HPP had a notable impact ($p < 0.05$) on the antioxidant capacity of the treated ripe jackfruit samples. The application of elevated pressure at 600 MPa for 20 min. increased the DPPH radical scavenging activity in HPP processed RJB to 91 ± 1.04 % DPPH radical scavenging activity and in RJP to 90.45 ± 1.05% DPPH radical scavenging activity. In comparison to the control sample, there were respective increases of 2.7% and 2.8% in DPPH radical scavenging activity in RJP and RJB.

Table.4.12 Effect of HPP on Total sugar of ripe jackfruit

Treatment		Total sugar	
Pressure (MPa)	**Holding time (min)**	**RJB**	**RJP**
300	5	25.49±0.92	22.62±0.26
600	5	25.45±0.91	22.65±0.82
300	20	25.46±0.67	22.63±0.60
600	20	25.50±1.11	22.68±0.99
238	12.5	25.50±1.16	22.64±1.04
662	12.5	25.50±1.17	22.67±1.04
450	2	25.48±0.92	22.67±0.82
450	23	25.46±0.67	22.65±0.60
450	12.5	25.48±1.11	22.64±0.99
450	12.5	25.49±0.88	22.64±0.78
450	12.5	25.47±1.16	22.65±1.04
450	12.5	25.50±0.92	22.64±0.82
450	12.5	25.48±0.67	22.64±0.60

RJB: Ripe jackfruit bulb; RJP: Ripe jackfruit pulp;Data shown are the mean±SD of three treatment repetitions

Changes in antioxidant activity are connected to variations in bioactive compounds such as total phenols, vitamin C, and flavonoids. Elevated pressure levels in HPP contribute to the increased extractability of specific antioxidant compounds by disrupting cell walls and releasing bioactive compounds. These components, recognized as significant contributors to antioxidant activity, play a vital role in fruit and vegetable products, and their impact is shaped by factors like estimation methods, juice matrix nature, and HPP technique parameters (Andres *et al*., 2016). It was reported that the utilization of moderate pressures on pineapple by-products resulted in an 85% boost in antioxidant activity (DPPH method), a 79% increase in FRAP method, and a 76% rise in ABTS method (Santos *et al*., 2022). However, some studies, conducted by Sánchez-Moreno *et al*. (2005), indicated minimal effects of HPP on antioxidant capacity.

The outcomes of the two-way ANOVA revealed that pressure and holding time significantly influenced the DPPH radical scavenging activity of RJB and RJP, as indicated by DPPH values ($p<0.05$) (Table C9 & C21). In the regression analysis, it was found that a second-order model was a good fit for the antioxidant capacity following HPP. The determination coefficients were R^2=0.94 ($p<0.05$) and R^2= 0.92 ($p<0.05$) respectively for RJB and RJP. The experimental data were best described by a second-order polynomial model given by the equation given below and the 3D graphical illustration is depicted in Fig 4.53 a and b

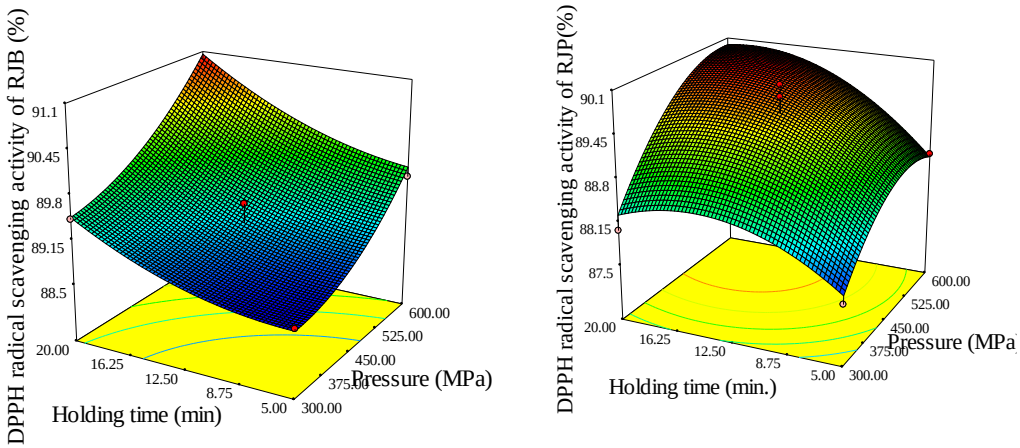
$DPPH_{RJB}$ radical scavenging activity (%)

$$= 89.23+0.69\ P+0.54Ht+0.093\ P\ Ht+0.29P^2+0.22\ Ht^2 \quad ..(4.64)$$

$DPPH_{RJP}$ radical scavenging activity (%)

$$=89.57+0.65\ P+0.50Ht+0.21\ P\ Ht-0.47\ P^2-0.47\ Ht^2 \quad \ldots(4.65)$$

Where RJB: jackfruit bulb; RJP: Ripe jackfruit pulp; P: Pressure in MPa and Ht: Holding time in min



(a) **(b)**

Fig.4.53 Effect of HPP on DPPH radical scavenging activity of RJB and RJP respectively

4.4.1.8 Effect of HPP on the firmness of RJB

The HPP had a significant impact ($p < 0.05$) on the firmness of the treated RJBs, as evident from Table 3. The initial hardness of untreated RJBs was 57.83 ± 2.6 N, while the hardness of those subjected to HPP increased from 57.16 ± 2.81 to 69 ± 3.16

N (Fig 4.54). In a two-way ANOVA, a notable impact of both pressure and holding time on sample hardness was identified (Table C10). However, there was no observed effect of the interaction between pressure and time. A nearly 19.31% increase was observed at 600 MPa, 20 mins. The model has an R^2 value of 0.97 ($P < 0.05$), showing a strong fit to the data. The significant variables are pressure and holding time. The F-value of 0.73 indicates that the lack of fit is not significant compared to the pure error, suggesting that the model sufficiently explains the relationship between the variables.

Following HPP, Pectin methylesterase (PME) is released and comes into contact with its substrate, which is highly methylated pectin. This results in de-esterification, occurring not only during the HPP but also after the pressure release. The texture firming was attributed to PME-initiated de-esterification, which facilitated the cross-linking of divalent metal ions with low-methoxyl pectins (Pérez-Pérez *et al*., 2019). It was noted that pressure treatment partially inactivated PME, enabling the interaction between the enzyme and substrate, initiating de-methylation and further contributing to textural firmness (Oey *et al*. 2008) Consequently, in the current study, the elevated treatment pressure exhibited a clear tendency toward creating a harder and firmer texture in RJBs. Ng *et al*. (2020) conducted similar studies on RJBs packed in vacuum skin (VS) and vacuum nylon (VN) packaging and observed an almost two-fold increase in hardness and chewiness after HPP. The regression equation for the texture of HPP-RJB is as follows:

Firmness of RJB (N) = $62.37+3.41\ P+2.15Ht+0.30\ PHt+0.69P^2-0.48Ht^2$… (4.66)

Where RJB: Ripe jackfruit bulb; RJP: Ripe jackfruit pulp; P: Pressure in MPa and Ht: Holding time in min

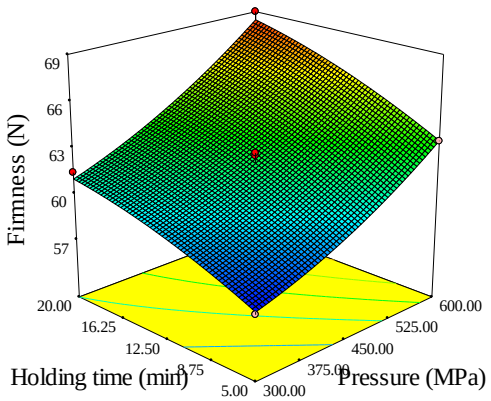


Fig .4.54 Effect of HPP on firmness of RJB

4.4.1.9 Effect of HPP on microbial activity of ripe jackfruit

The yeast and mould counts in untreated RJBs and RJP were 4.3 ± 0.15 and 4.4 ± 0.11 log CFU/g, respectively. However, for HP-treated samples, the microbial counts were all below the detection limit. The total log reduction in yeast and mold count varied from 3.87 ± 0.17 to 6.20 ± 0.035 log CFU/g for RJB (4.56a) and 4.3 ± 0.24 to 6.20 ± 0.14 log CFU/g for RJP (Fig 4.56b). After HPP at or over 600 MPa for 20 mins, the counts of microbial populations were significantly ($p<0.05$) reduced in treated RJB and RJP. Conversely, HPP treatments resulted in microbial counts (TAM) within allowable limits across all treatments (ie., <1 log CFU/g). The TAM in control samples were 4.51±0.16 and 4.73± 0.25 CFU/g, respectively in RJB and RJP. There was a significant decline in TAM observed in treated RJB and RJP concerning pressure and time ($p<0.05$). The total log reduction of TAM in the treated RJB and RJP was reported to be 4.1 ± 0.18 to 6.4 ± 0.23 log CFU/g (Fig 4.55a) and 4.1 ± 0.10 to 5.93 ± 0.0.23 log CFU/g (Fig 4.55b) from the initial population, respectively, in RJB and RJP. A substantial decline in cell counts occurred after pressurisation and was noticeable at 600 MPa, for 20 min ie., 6.4 ± 0.23 log CFU/g and 5.93 ± 0.0.23 log CFU/g respectively in RJB and RJP, and the least reduction, 4.1± 0.18 log CFU/g, was observed at a lower pressure of 300 MPa. According to Daher *et al*. (2017), HPP causes alterations in cellular membranes and interrupts cellular functions, specifically those associated with reproduction, resulting in bacterial death. Furthermore, pressure affects energy availability within cells by influencing biochemical reactions responsible for energy production. Li *et al*. (2010) reported a significant reduction in the total aerobic bacterial count at 400 MPa and 600 MPa in high-pressure treated sour Chinese cabbage for 10–30 min, while Kaushik *et al*. (2014) observed that microbial counts in mango pulp decreased to 4.6 ± 0.24 log cycles after applying 600 MPa for 5 min. In this investigation, microbial counts in both high-pressure processed RJB and RJP were detectable, confirming the effectiveness of HPP against microbial growth. The regression equation for the microbial activity of HPP-RJB is as follows:

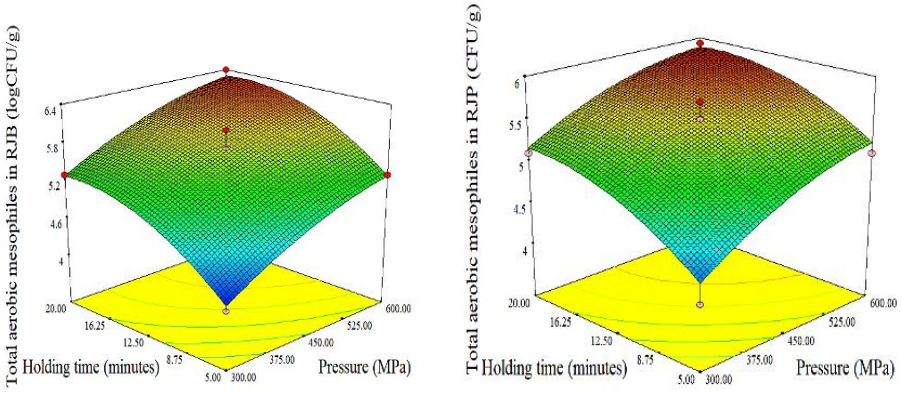
$$TAM_{RJB}\,(\log CFU/g) = 5.74 + 0.53P + 0.53Ht - 0.025PHt - 0.15P^2 - 0.32Ht^2 \quad \ldots (4.67)$$

$$TAM_{RJP}\,(\log CFU/g) = 5.51 + 0.40P + 0.37Ht - 0.042PHt - 0.15P^2 - 0.20Ht^2 \quad \ldots (4.68)$$

$Yeast/mold_{RJB}$ (log CFU/g) =5.10+0.55P+0.55Ht+0.22PHt-0.014P^2-0.24Ht^2 … (4.69)

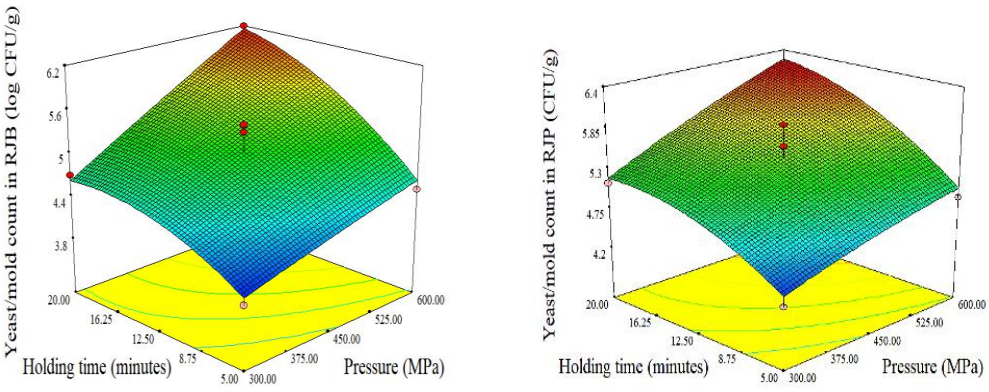
$Yeast/mold_{RJP}$ (log CFU/g) =5.50+0.42P+0.49Ht+0.13PHt-0.050P2-0.22Ht^2 … (4.70)

Where RJB: Ripe jackfruit bulb; RJP: Ripe jackfruit pulp; P: Pressure in MPa and Ht: Holding time in min; TAM-Total aerobic mesophiles. The R2 value and ANOVA table of HP processed ripe jackfruit is given in Appendix C)



(a) **(b)**

Fig.4.55 Effect of HPP on TAM of RJB and RJP respectively



(a) **(b)**

Fig .4.56 Effect of HPP on yeast/mold of RJB and RJP respectively

4.4.1.10 Effect of HPP on rheological property of ripe jackfruit

The rheological properties of RJP subjected to HPP were systematically evaluated under different treatment conditions, with a particular focus on viscosity and shear rate. The recorded viscosity of RJP varied within the range of 43.35 ± 0.85 to 60.53 ± 0.80 Pa.s, as depicted in Fig. 4.57 The experimental data were effectively analyzed using the power law model, yielding a consistency index (K) of 67.74 ± 0.58 and a flow behavior index (n) of 0.72. These values confirm the shear-thinning nature of RJP, classifying it as a non-Newtonian fluid due to its dependence on shear rate rather than maintaining a constant viscosity.

Fig. 4.58 presents the impact of HPP on viscosity (Pa.s) as a function of shear rate (1/s) for different treatment conditions (T1 to T9) alongside a control sample. The observed results clearly demonstrate the shear-thinning behavior of RJP, with viscosity increasing significantly post-HPP in comparison to fresh pulp, which had an initial viscosity of 42.77 ± 0.76 Pa.s. At lower shear rates, treatments T4 and T6 exhibited the most pronounced increase in viscosity relative to other conditions (Fig. 4.58). Notably, treatment T6 exhibited the highest viscosity of 60.53 ± 0.80 Pa.s, highlighting the synergistic effect of both pressure and holding time in enhancing viscosity. These findings are consistent with previous studies on pressurized apple purees, where viscosity initially increased and later stabilized at elevated shear rates

As the shear rate increased, the viscosities of all treated samples gradually converged toward lower values, reinforcing the shear-thinning behavior of RJP. It was observed that treatments processed under higher pressures and extended holding times resulted in greater viscosity enhancement, while lower-pressure treatments such as T1 and T3 exhibited relatively lower viscosity values. The general trend indicates that increasing both pressure and holding time leads to a viscosity increase, albeit with more complex interactions due to the presence of significant quadratic terms influencing the response.

Both untreated and treated RJP consistently exhibited shear-thinning characteristics, aligning with previously reported observations in fruit purees Steffe (1996) The increase in viscosity among treated samples may be attributed to the improved solubilization of polysaccharides such as starch and pectin, as suggested by

prior studies Zhou *et al*. (2017). Similar viscosity-enhancing effects have been documented by Krebbers *et al*. (2003) and Moussa-Ayoub *et al.* (2017), where HPP treatment contributed to structural modifications leading to viscosity enhancement. The observed viscosity changes could be attributed to reduced enzymatic activity, particularly a decline in polygalacturonase (PG) activity, which plays a role in cell wall degradation. A related study conducted by Hsu *et al*. (2008) demonstrated a strong association between PG activity and the viscosity of tomato juice subjected to HPP. The increase in viscosity following HPP is likely due to the release of cellular components as a result of cell wall permeabilization under high pressure, as previously noted by other researchers (Landl *et al*., 2010).

Statistical analysis using analysis of variance (ANOVA) confirmed a highly significant model ($F = 78.21$, $p < 0.0001$ and $R^2 = 0.98$), establishing a strong correlation between viscosity changes and both pressure and holding time. The final viscosity equation derived from the analysis is as follows:

$$\text{Viscosity (Pa.s)} = 49.06 + 4.05P + 4.07Ht - 0.46\,PHt + 1.03P^2 + 2.73\,Ht^2 \quad \ldots (4.71)$$

Where: P = Pressure (MPa) Ht = Holding time (min)

This equation illustrates that both pressure and holding time exert significant positive linear effects on viscosity. Furthermore, their quadratic terms contribute to the response surface curvature, indicating that viscosity undergoes more pronounced changes at extreme values of either factor. These findings emphasize the importance of optimizing HPP conditions to achieve the desired rheological properties in RJP, with potential implications for its application in food processing and formulation.

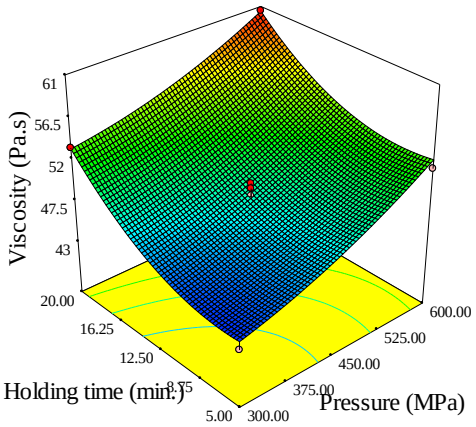
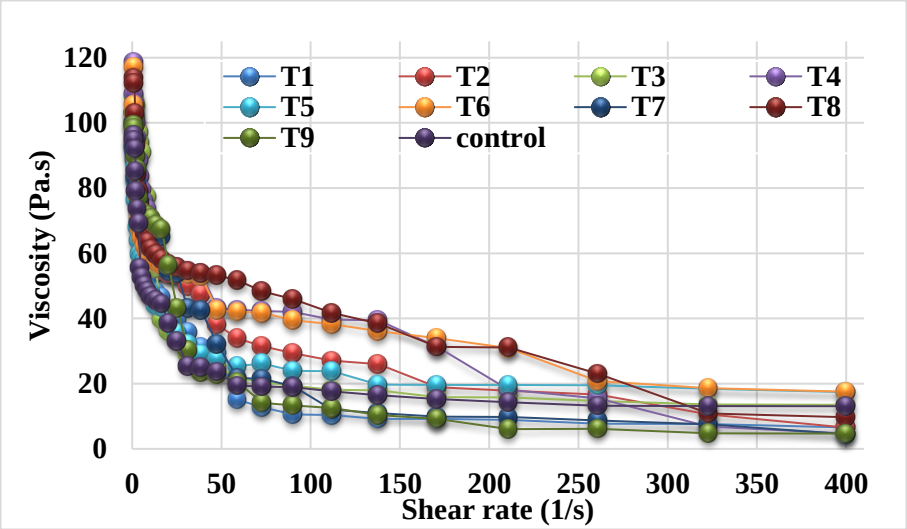


Fig. 4.57 Effect of HPP on viscosity of RJP



T1:300 MPa/5 min, T2:600 MPa /5 min, T3:300 MPa /20 min, T4:600 MPa /20 min, T5:238 MPa /12.5 min, T6:662 MPa /12.5 min, T7:450 MPa /2 min, T8:450 MPa /23 min, T9:450 MPa /12.5 min

Fig.4.58 Viscosity of HPP processed RJP as a function of shear rate

4.4.1.11 Sensory analysis

The results of the sensory evaluation of the samples are depicted in Fig.4.59 and 4.60. According to sensory analysis, treatment T_4 (600 MPa for 20 min) in high-pressure processed RJB achieved an overall acceptability score of 7.30, while T_6 (600 MPa for 12.5 min) scored the highest for RJP with an overall acceptability of 6.8, which was the highest score among other samples except for the control.

The control sample achieved the highest scores of 8.5 and 7, respectively for RJB and RJP. Lower scores in visual colour were observed in T_4 and T_6 for both RJB and RJP (Fig 4.60), attributed to a deviation from yellow to transparent colour due to the extraction of micelles post-processing. Textural scores were notably high for treatments with higher pressures, particularly at 600MPa/20 min, with a score of 7.2. Taste and aroma scores were nearly equivalent to the control for treated RJB and RJP, indicating that HPP did not significantly alter the taste and aroma of the treated jackfruit samples.

The sensory scorecard for the nine-point hedonic scale is provided in the appendix, along with a table displaying the sensory scores for each treatment. Statistical

analysis shows that all p-values are greater than 0.05, there is no statistically significant difference in sensory attributes across the different treatments. This suggests that high pressure processing do not significantly impact color, aroma, taste, texture, or overall acceptability in RJB and RJP.

Where T1:300 MPa/5 min, T2:600 MPa /5min, T3:300 MPa /20 min, T4:600 MPa /20 min, T5:238 MPa /12.5 min, T6:662 MPa /12.5 min, T7:450 MPa /2 min, T8:450 MPa /23 min, T9:450 MPa /12.5 min.

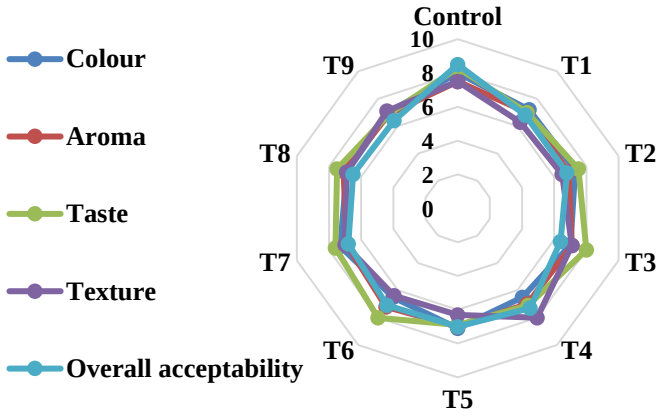


Fig. 4.59 Sensory score card for HP processed RJB

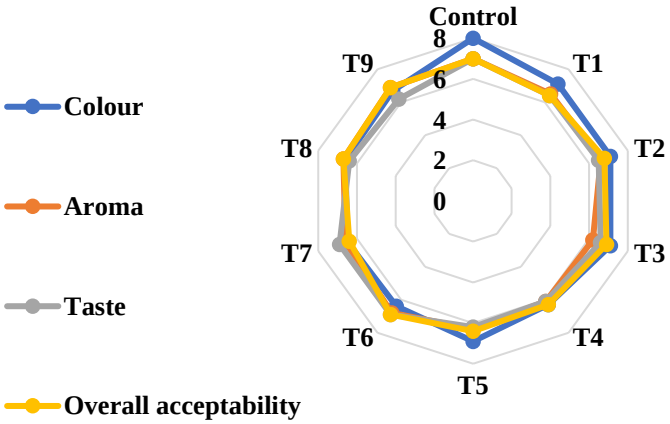


Fig.4.60 Sensory score card for HP processed RJP

4.4.2 Optimisation of the HPP ripe jackfruit

The numerical optimisation of the HPP of RJB and RJP was done based on the RSM approach. The optimization criteria for RJB were established to prioritize maximum preservation of bioactive compounds and minimal levels of microbial count and BI For the RJP, the focus was on maximizing bioactive compounds while minimizing microbial load. The remaining parameters were restricted to the limits observed in this study. The important values for bioactive compound retention and microbial stability were prioritized, aiming for a maximum desirability value, which was 0.952 for RJB and 0.839 for RJP. This suggests a stronger adherence to the established goals. At the optimized HPP conditions of 600 MPa/20 min. for RJB and 600 MPa/15 min for RJP, significant improvements were noted. For RJB, the bioactive compounds were effectively retained, with higher log reduction of TAM (6.3 log CFU/g) and yeast/mold count (6.1 log CFU/g), while firmness was enhanced. Similarly, for RJP, maximum bioactive compound retention and minimal microbial load (5.87 log CFU/g) and yeast/mold count (6.07 log CFU/g) were observed under the optimised conditions.

4.4.3 Cost analysis of high pressure processed ripe jackfruit

The production cost for HPP ripe RJBs and RJP was estimated by considering both fixed and variable costs. For HPP ripe RJBs, the cost was determined to be ₹3,758.62 per 500 g pack and ₹1,879.31 per 250 g pack. Similarly, for HPP ripe RJP, the production cost was calculated as ₹4,176.72 per 500 g pack and ₹2,088.36 per 250 g pack (Appendix G3 & G4). These costs include expenses related to fixed costs such as depreciation, interest, repairs, maintenance, insurance, and taxes, as well as variable costs including electricity, labour, raw materials, and packaging. However, these cost estimations are based on processing carried out using a lab-scale HPP machine with limited capacity. This significantly inflates the production cost and makes the benefit-cost ratio (BCR) calculation impractical for commercial comparison. A commercial-scale HPP system with higher throughput could substantially reduce the per-unit cost and improve economic feasibility.

4.5 Effect of storage on HPP of ripe jackfruit

The HPP of ripe jackfruit samples was conducted following established protocols, and the optimised samples were subsequently stored under refrigerated conditions for a storage study. The treatment conditions identified as optimal were 600 MPa for 20 min. for RJB and 600 MPa for 15 min. for RJP. To assess the quality changes of the stored samples, evaluations were performed over a 40-day period, with assessments occurring every 10 days. The results and discussions regarding these findings are elaborated in the following section.

4.5.1 Effect of storage on pH, TA, and TSS of ripe jackfruit

The pH variation in high-pressure processed ripe RJP and bulb over different storage periods was analysed. The pH of the fresh pulp dropped from 5 ± 0.2 to 3.2 ± 0.1 over 10 days of storage, and the pH of the fresh ripe RJB decreased from 5.1 ± 0.2 to 4 ± 0.1 in 15 days (Fig 4.61), and spoiled thereafter. As noted by Subasi *et al*., (2017), initial investigations revealed non significant ($p>0.05$) deviations in pH values during the first 40 days of storage. For the pulp, the pH values ranged from 4.66 ± 0.21 to 4.99 ± 0.17 during storage. Despite these fluctuations, the variations were not statistically significant ($p>0.05$), indicating that the pulp maintained a relatively stable pH over the 40-day storage period. Similarly, the bulb exhibited pH values ranging from 4.42 ± 0.14 to 4.59 ± 0.16 with no significant differences across the storage days. This stability suggests that high-pressure processing effectively preserves the pH of both the pulp and bulb, thereby potentially extending the shelf life without compromising quality. This phenomenon may be attributed to microbial metabolism in the pulp, as discussed by Liu *et al*. (2016) . The observed decrease in pH during storage of the HPP-treated RJP is consistent with findings in other HPP-treated fruit products, such as avocado paste and Maoberry juice, as reported by Jacobo-Velazquez and Hernandez-Brenes (2010) and Chaikham and Prangthip.(2015), respectively. These declines may be associated with the migration of organic acids and microbial activities during storage.

Similarly, the study investigated the TA of high-pressure processed ripe RJP and bulb over various storage periods. The TA of fresh pulp initially measured at 0.51±0.02%, increased to 0.68±0.04% within the first 10 days of storage, while the

bulb's TA was 0.50±0.01%, rising to 0.63±0.01% by the 15th day. For the bulb, the TA values ranged from 0.69±0.01% on the 0th day to 0.72±0.02% on the 40th day. The ANOVA results indicated that the differences in TA values over time were not statistically significant. For RJP, the Duncan post hoc test showed two homogeneous subsets—0th, 10th, and 20th days in the first, and 30th and 40th days in the second—suggesting a gradual increase in TA over time, while for RJB, it revealed that all storage periods formed a single homogeneous subset, indicating that the changes in TA were not substantial over time. Varela-Santos *et al*. (2012) also reported similar findings with high-pressure processed pomegranate juice, noting that both pH and TA remained stable during refrigerated storage over a period of 15 days.

The TSS ranged from 23.09±0.11 to 23.28±0.14 °Brix for high pressure processed RJP, and from 21.04±1.05 to 21.31±0.05 °Brix for RJB over the 0th to 40th day of storage, as shown in Table 1. ANOVA analysis indicated no significant ($p>0.05$) differences in TSS values among the storage periods, suggesting that the storage duration did not notably impact the TSS content of either RJP or RJB. This stability in TSS implies that both products maintained consistent quality and composition throughout the storage period, essential for product integrity and consumer satisfaction. According to Bi *et al*. (2020), high-pressure processing of mango smoothies resulted in a slight but statistically insignificant increase in TSS compared to untreated samples.

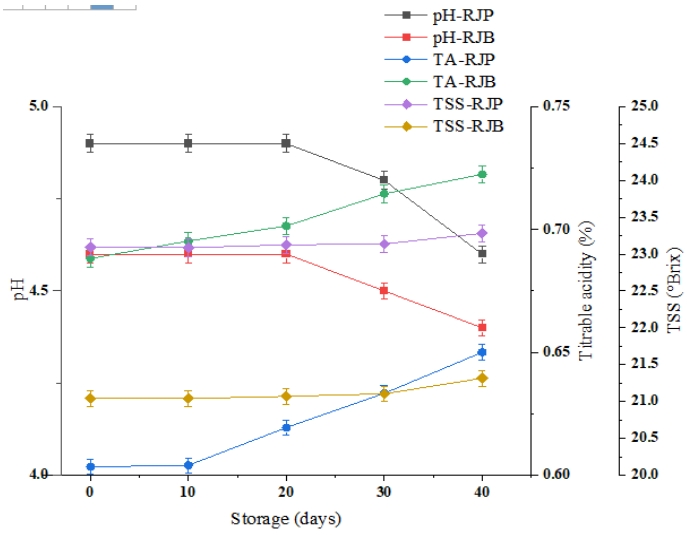


Fig. 4.61 Effect of storage on pH, TA, and TSS of HP processed RJP and RJB

4.5.2 Effect of storage on ΔE of ripe jackfruit

During storage, the ΔE of ripe RJB and pulp was observed. The colour deviation in the high-pressure processed RJP increased from an initial value of 2.78 ± 0.24 on the 0th day to 3.13 ± 0.06 on the 40th day. In the RJB, the colour deviation rose from 5.57 ± 0.11 on the 0th day to 6.21±0.72 on the 40th day. The control sample of fresh pulp exhibited an ΔE increase from 0 to 6.77 ± 1.11 (Fig. 4.62), while the fresh bulb showed an increase from 0 to 6.9 ± 2.16. Although there was an increase in ΔE in both the bulb and pulp during storage, the changes were not statistically significant. This indicates that the effect of storage on the ΔE of RJB and pulp, compared to the fresh samples, was minimal and did not result in significant variation. Ibarz *et al*. (2000) reported that various factors can contribute to these changes, including enzymatic and non-enzymatic browning, Maillard reactions occurring during storage, and the degradation or polymerisation of polyphenols. Szczepańska *et al*. (2022) observed similar results during the storage of HPP apple juice. Processed at 600 MPa for 5 minutes, the ΔE value of the juice increased from 4.14 to 10.53 after 12 weeks of storage.

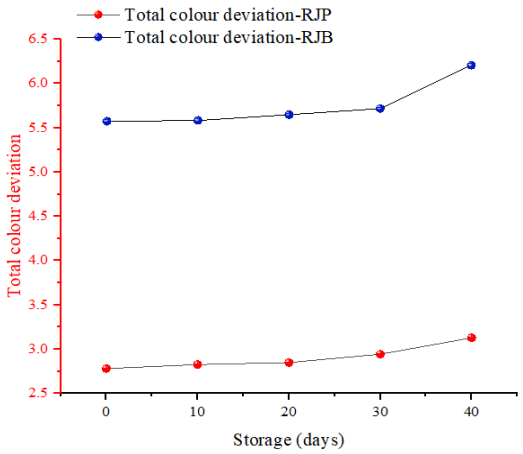


Fig. 4.62 Effect of storage on total colour deviation of High pressure processed RJP and RJB

4.5.3 Effect of storage on AA of ripe jackfruit

The initial AA content of fresh RJP and bulb were 7.84±0.19 mg/100 g and 13.68 ±0.43 mg/100 g, respectively. During the storage period, the AA content of the pulp varied from 7.62 ± 0.17 mg/100 g on the 40th day to 9.47±0.48 mg/100 g on the

0th day, while for the bulb, it ranged from 14.85±0.21 mg/100 g on the 40th day to 16.65±0.33 mg/100 g on the 0th day. The percentage retention of AA from the 0th day to the 40th day was also determined for both pulp and bulb. In the case of the pulp, where the AA content decreased from 9.46 ±0.48 mg/100 g on the 0th day to 7.62±0.17 mg/100 g on the 40th day, the retention of AA was approximately 80.45%. Similarly, for the bulb, with AA content decreasing from 16.65 ±0.33 mg/100 g to 14.85±0.21 mg/100 g over the same period, the retention of AA was approximately 89.14%. These findings illustrate the relative stability of ascorbic acid in RJP and bulb during the 40-day storage period under HPP, indicating that a significant portion of the initial AA content remains preserved despite storage-related losses. The deterioration of AA in stored fruits, including jackfruit, can be attributed to several factors as suggested by Sakhale *et al* (2012). These include exposure to light, oxidation of AA to dehydroascorbic acid, and the influence of enzymes such as cytochrome oxidase, ascorbic acid oxidase, and peroxidase. Additionally, both aerobic and anaerobic reactions play roles in AA degradation. According to Szczepanska *et al*. (2022), the concentration of vitamin C in cloudy apple juice treated at 600 MPa showed a significant degradation (60–80%) during storage after three weeks at 4°C. In industrial practice, the decline in AA content often determines the shelf life of juice samples, with a 50% decrease generally marking the point of reduced quality. Jackfruit samples treated with HPP can typically maintain acceptable quality for up to 40 days of refrigerated storage before reaching this critical threshold. This underscores the effectiveness of HPP in preserving AA levels compared to traditional methods, ensuring prolonged freshness and nutritional quality in stored ripe jackfruit.

The ANOVA revealed a highly significant effect of storage time on the AA content for both RJB and RJP ($p < 0.001$). Post hoc tests using Duncan's method demonstrated three distinct homogeneous subsets for both RJB and RJP , indicating that the rate of AA degradation differed significantly across storage times. For the RJP, the lowest AA content was observed on the 40th day, with a mean value of 7.62 ± 0.17 mg/100g, and the highest content on the 0th day, with a mean value of 9.47 ± 0.48 mg/100g. Similarly, for the RJB, the lowest AA content was recorded on the 40th day (14.85 ± 0.21 mg/100g) and the highest on the 0th day (16.65 ± 0.33 mg/100 g).

These findings indicate that HPP at 600 MPa for 20 min (RJP) and 15 minutes (RJB) effectively retained a significant portion of AA during the initial stages of storage but showed a marked decrease as the storage period extended to 40 days.

4.5.4 Effect of storage on TPC of ripe jackfruit

The TPC of high-pressure processed RJP and RJB was evaluated over a 40-day refrigerated storage period. The initial TPC for fresh jackfruit pulp was recorded at 64.78 ± 2.33 mg GAE/g, which decreased significantly to 52.14 ± 1.59 mg GAE/g by the 10^{th} day of storage. For the RJB, the initial TPC was 61.63 ± 0.34 mg GAE/g, which declined to 53.25 ± 0.25 mg GAE/g after 20 days of storage. The TPC values for the high-pressure processed RJP ranged from 70.08 ±0.37 mg GAE/g on the 0^{th} day to 61.15 ±3.29 mg GAE/g on the 40^{th} day. For the high-pressure processed RJB, the TPC values ranged from 66.03±0.64 mg GAE/g on the 0^{th} day to 62.72±0.62 mg GAE/g on the 40^{th} day (Fig 4.63). ANOVA analysis indicated a significant reduction in TPC in RJP and RJB respectively over the storage period ($p < 0.001$). Post hoc analysis with Duncan's test showed that the TPC on the 40^{th} day (61.15±3.29 mg GAE/g and 62.72±0.62 mg GAE/g) was significantly lower than that on the 0^{th} day (70.08±0.37 mg GAE/g and 66.03±0.64 mg GAE/g). This slight decrease could be attributed to the formation of partially soluble polymers during storage, which interact with the Folin–Ciocalteau reagent (Pérez-Vicente *et al*., 2004). These findings align with previous reports by Ozgen *et al*. (2008) and` *et al*. (2009) Varela-Santos *et al*. (2012), who observed similar levels of total phenols. The TPC values indicated a more pronounced reduction in the RJP compared to the RJB over the 40-day storage period. Specifically, the RJP showed a 13% reduction in TPC, whereas the RJB showed only a 5% reduction. The retention of phenolic content in the RJP was less compared to the bulb, suggesting different rates of phenolic degradation or stability between the two forms of jackfruit.

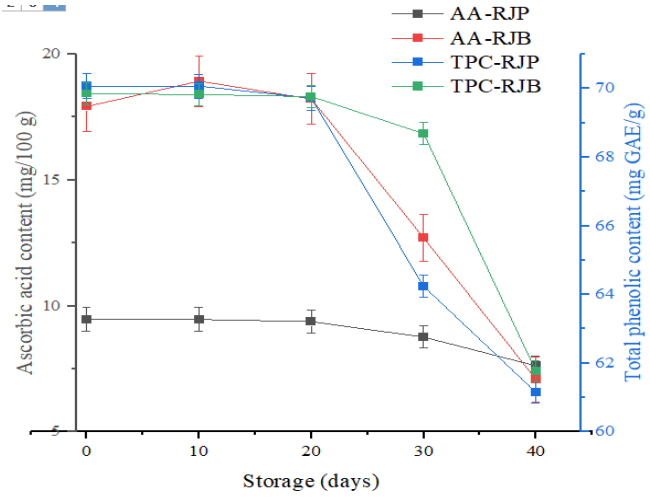


Fig. 4.63 Effect of storage on AA and TPC of HP processed RJP and RJB

4.5.5 Effect of storage on total sugar content of ripe jackfruit

The total sugar content in HP processed RJP and RJB was evaluated over a refrigerated storage period of 40 days, with initial values for the pulp and bulb being 22.62±0.72% and 25.01±0.68%, respectively. In the pulp, the total sugar content decreased from 22.68±0.14% on the 0^{th} day to 21.91±0.72% by the 40^{th} day (Fig 4.64), representing a 3% reduction. In contrast, the bulb exhibited a reduction in total sugar from 25.49± 0.70% initially to 24.66±0.75% after 40 days, a 3.26% decrease was observed, indicating a retention of around 96.71% of its initial sugar content. The variation in sugar content observed in the treated jackfruit samples can be attributed to the varying levels of surviving microbes. By the end of the storage period, the increased number of viable microbes likely led to a more pronounced decline in sugar content. This trend aligns with findings by Wu *et al*. (2021), who reported less than a 9% reduction in glucose and sucrose content in high-pressure processed pineapple juices stored under refrigerated conditions, consistent with previous observations by Huang *et al*. (2017).

ANOVA results showed no significant differences in the total sugar content between the storage intervals for both pulp ($F = 0.630$, $p = 0.652$) and bulb ($F = 1.174$, $p = 0.379$). Duncan's post hoc test further confirmed the homogeneity of total sugar content within each group, indicating consistent sugar levels across the different storage periods.

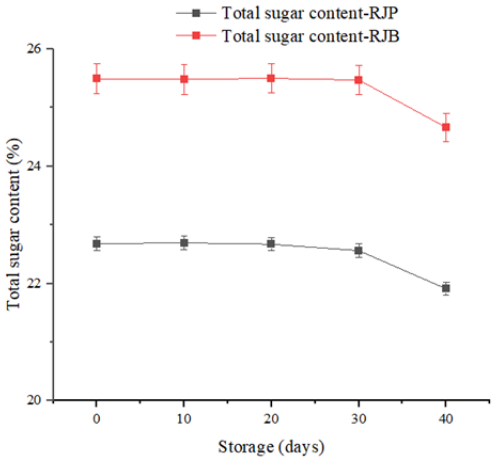


Fig. 4.64 Effect of storage on Total sugar content of HP processed RJP and RJB

4.5.6 Effect of storage on texture of ripe jackfruit

The firmness of RJB was measured as the textural property of the sample during its storage. The effect of HPP at 600 MPa for 20 minutes on the textural properties of RJBs during refrigerated storage was investigated and compared with a control sample. At the initial storage period of 0^{th} day, the texture of the HPP-treated sample (68.35±0.87 N) was significantly higher compared to the control (57.83±0.68 N). This trend continued throughout the storage period. After 10 days, the control sample showed a minor decrease in texture (57.64±0.76 N), whereas the HPP-treated sample maintained a relatively stable texture (68.35± 2.52 N) after 10 days. A marked decrease in texture was observed in the control sample by the 20^{th} day (46.85±1.47 N), indicating a significant loss in firmness of control sample. (Fig 4.65). In contrast, the HPP-treated sample retained its texture well (68.00±2.00 N) at the same time point. The observed reduction in texture in the RJB during storage can be attributed to enzymatic and non-enzymatic depolymerization of pectin and leaching from the RJP. Similar findings were reported by Gao *et al*. (2016), where pressurized strawberries, after storage for 45 and 60 days at 4°C, showed decreased hardness. Statistical analysis using Levene's test

confirmed the homogeneity of variances (p = 0.278), and ANOVA results indicated no significant differences in texture between the storage periods (F(4,10) = 0.095, p = 0.982). Post hoc tests using Duncan's method identified that all storage periods formed a single homogeneous subset, indicating no significant differences in texture between any of the storage periods. These results suggest that HPP treatment at 600 MPa for 20 minutes effectively preserves the textural quality of RJBs during extended refrigerated storage, highlighting its potential as a method for extending the shelf life of fresh produce.

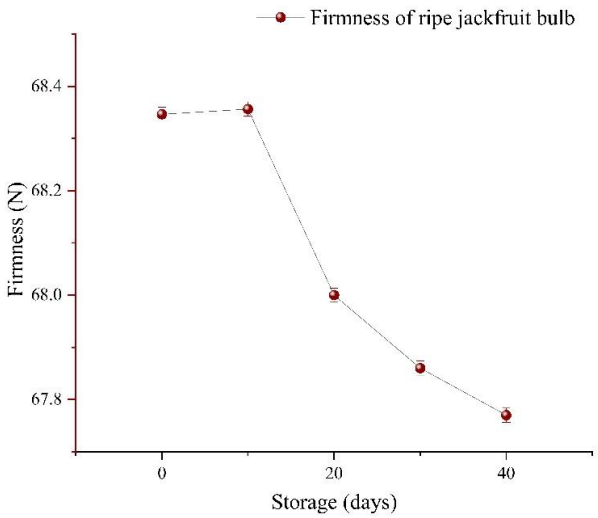


Fig.4.65 Effect of storage on firmness of High pressure processed RJB

4.5.7 Effect of storage on microbial analysis of ripe jackfruit

The microbiological quality of optimized samples of RJB and RJP after HPP and control was determined by monitoring the total aerobic bacteria and yeast and mould counts in the samples (Table 4.13). The mean initial populations of viable aerobic bacteria in RJP and RJB were 3.36±3.25 and 3.18±3.06 log CFU/g, respectively, while the initial populations of yeast and mold were 3.10 ±2.58 and 3.11± 2.11 log CFU/g, respectively. Over the storage period, the control samples showed a significant increase in microbial population and yeast and mold counts. The control samples of fresh pulp were stable up to 10 days, and the bulb was stable only up to 15 days under refrigerated storage. For the RJP control, the microbial population increased to an average of

8.18±3.26 log CFU/g by day 10. In the case of RJB control, the microbial population increased to an average of 8.76 ± 1.28 log CFU/g by day 15.

The HPP at 600 MPa for 15 and 20 min significantly reduced the microbial population. For RJP processed at 600 MPa for15 min, the microbial counts were <1 log CFU/g up to 20 days, and then increased to 2.48±1.02 log CFU/g by day 30 and 3.88±1.07 log CFU/g by day 40. Similarly, for RJB processed at 600 MPa/20 min, microbial counts remained <1 log CFU/g up to 20 days increasing to 2.55±1.74 log CFU/g on day 30 and 2.66±1.20 log CFU/g on day 40. The increase in the number of total aerobic bacteria (TAB) in ripe jackfruit samples is likely due to the reproduction of surviving cells and the recovery of injured cells (Wu *et al*., 2021).

The yeast and mold counts in control samples also increased over time, with RJP control showing an increase from 3.10 ±2.58 log CFU/ml on day after processing to 6.23±2.85 log CFU/ml on day 10,. RJB control samples showed an increase from 3.11±2.11 log CFU/g on day 0 to 6.38±2.07 log CFU/g on day 15. In contrast, HPP-treated samples showed significantly lower yeast and mold counts. For RJP processed at 600 MPa/15 min, counts remained <1 log cfu/ml up to 20 days, then increased to 2.50 ±2.78 log cfu/g on day 40. RJB processed at 600 MPa for 20 min also maintained counts of <1 log cfu/g up to 20 days, increasing to 2.79±2.09 log cfu/g by day 40. These results indicate that HPP at 600 MPa significantly reduces the microbial population and yeast and mold counts in RJP and RJB, maintaining lower levels over the storage period compared to the control samples. Similarly, Liu *et al*. (2016) reported that yeast and mold counts in cucumber juice treated by HPP (500 MPa/5 min) were undetectable during the first 20 days of storage at 4°C. However, a resurgence of yeast and mold counts and coliforms was noted in the end of storage period.

Wu *et al*. (2021) observed an upward trend in the counts of total aerobic bacteria (TAB) in high-pressure processed pineapple fruit juices during 28 days of storage, with counts reaching 2.02 log CFU/mL. The study also noted that yeast, mold, and coliforms were undetected in HPP- for the first 21 days, but were measurable by day 28, aligning with previous research on microbial resurgence during storage.

Table. 4.13 Effect of storage on microbial activity of HP processed RJP and RJB

Sample	Treatments	Storage time (days)	Total aerobic bacteria (log10 CFU/mL)	yeast and mould counts (log10 CFU/mL)
RJP	Control (Fresh RJP)	0	3.36±3.25	3.10±2.58
		10	8.18±3.26	6.23±2.85
	HPP (600MPa for 15 min)	0	<1	<1
		10	<1	<1
		20	<1	<1
		30	2.48±1.02	2.50±2.78
		40	3.88±1.07	3.05±1.78
RJB	Control (Fresh RJB)	0	3.18±3.06	3.11±2.11
		10	6.60±2.14	3.98±2.04
		15	8.76±1.28	6.38±2.07
	HPP (600MPa for 20 min)	0	<1	<1
		10	<1	<1
		20	<1	<1
		30	2.55±1.74	2.29±2.23
		40	2.66±1.20	2.79±2.09

Data shown are the mean±SD of three treatment repetitions

4.5.8 Effect of storage on sensory analysis of ripe jackfruit

The sensory analysis of high-pressure processed RJB and RJP was conducted over a storage period of 40 days, assessing attributes such as colour, aroma, consistency/texture, and overall acceptability.For RJB, the colour scores showed a slight decline from 6.5 ± 0.25 on day 1 to 6.04 ± 0.64 by day 40 (Fig 4.66). This decrease indicates a gradual loss of visual appeal, likely due to oxidative changes and pigment degradation, which are common in fruit products during storage (Cumplido-Laso *et al*., 2022). The aroma score also decreased from 7.00 ± 0.54 on day 1 to 6.31 ± 0.63 by day 40, suggesting a loss of volatile compounds responsible for the fresh aroma of the RJB,

potentially influenced by storage conditions and the high-pressure processing itself (Barros-Castillo *et al*, 2023). Consistency/texture scores declined from 7.1 ± 0.62 on day 1 to 6.11 ± 0.85 by day 40, with these changes attributed to enzymatic activities and moisture loss, impacting the structural integrity of the RJB (Ng *et al*., 2020). Consequently, the overall acceptability score dropped from 7.3 ± 0.88 on day 1 to 6.01 ± 0.76 by day 40, reflecting the cumulative effects of changes in colour, aroma, and texture on sensory appeal over time.Similarly, the colour scores for RJP decreased from 6.4±1.02 on day 1 to 5.9±1.11 by day 40, indicating pigment degradation and potential browning reactions that affect the visual quality of the pulp (Cumplido-Laso *et al*., 2022). The aroma scores also fell from 6.8±0.14 on day 1 to 6.00±1.03 by day 40, suggesting a loss of freshness and aromatic compounds, likely due to the volatilization of these substances and possible microbial activities during storage (Zhao *et al.*, 2024). The consistency/texture scores for RJP showed a notable decline from 6.9±0.89 on day 1 to 6.00±1.03 by day 40, linked to the breakdown of cell walls and pectin substances, resulting in a softer and less desirable texture (Wang *et al*., 2018).

Overall acceptability for RJP decreased from 6.8±0.15 on day 1 to 5.81±0.66 by day 40, indicating a significant decline in sensory appeal over the storage period due to combined changes in colour, aroma, and texture (Fig 4.67).The decreasing sensory scores for both RJB and RJP highlight the challenges in maintaining the sensory quality of HPP jackfruit products over time. The decline in colour can be attributed to oxidative reactions and enzymatic browning, while aroma loss is likely due to the volatilization of aroma compounds and potential microbial activities. Changes in consistency/texture are often a result of enzymatic breakdown of cell wall components and moisture migration, exacerbated by high-pressure processing. Overall, while HPP can extend the shelf life of jackfruit products by inactivating microorganisms and enzymes, the sensory quality deteriorates over time. This underscores the need for optimized storage conditions and the potential use of preservatives to maintain the sensory attributes and consumer acceptability of HPP jackfruit products over extended periods.

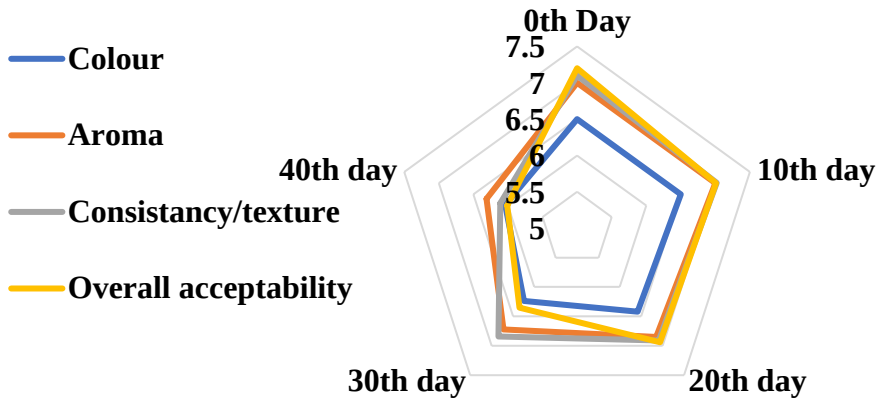


Fig.4.66 Effect of storage on sensory score of HP processed RJB

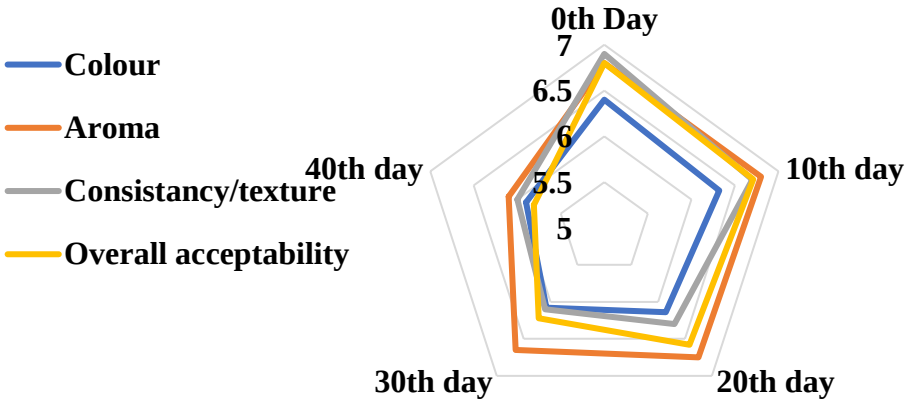


Fig.4.67 Effect of storage on sensory score of HP processed RJP

The study indicated that ripe jackfruit samples maintained their quality for over 40 days. The physicochemical properties exhibited minimal deterioration during storage, and the stored products were microbiologically safe, with microbial counts below 1 log CFU/g. The TPC decreased by only 13 and 5% after 40 days, comparable to the control. AA retention was approximately 80-89% in the stored samples. Sensory scores remained high for up to 30 days.

EXPERIMENT-III

4.6 STANDARDISATION OF PL FOR RJP

The collected ripe jackfruit intended for processing underwent a thorough analysis of its physico-chemical properties, and the results of this analysis have been systematically tabulated and detailed below (Table 4.13). This comprehensive examination involved assessing various physical and chemical attributes of the fruit, providing a detailed understanding of its composition and characteristics before further processing.

Table 4.14 Physico-chemical and microbial properties of fresh RJP prior to PL

Sl.No	Parameters		RJP
1	pH		5.31 ± 0.19
2	TSS (ºBrix)		23.80 ± 1.15
3	TA (%)		0.54 ± 0.02
4	Total sugar (%)		22.42 ± 0.98
5	AA (mg/100 g)		16.85 ± 0.45
		L*	58.69 ± 1.55
7	Colour	a*	7.63 ± 0.20
8		b*	57.45 ± 2.50
9	% DPPH scavenging activity		84.32 ± 3.68
10	TPC (mg GAE/g)		65.14 ± 2.89
11	TFC (mg RE/g)		20.54 ± 0.53

Where, TSS-Total soluble solids, TPC-Total phenolic content, TFC-Total flavonoid content; AA- Ascorbic acid; values are expressed in mean ±SD

4.6.1 Effect of PL on quality characteristics of ripe jackfruit

46.1.1 Effect of PL on pH, TA and TSS of RJP

In the investigation of PL treated RJP, standard analytical methodologies were employed to evaluate pH, TA, and TSS, as delineated in the preceding chapter. The control sample exhibited a pH value of 5.31 ± 0.19, a TA of 0.54 ± 0.02%, and a TSS value of 23.80 ± 1.15 °Brix (Table 4.15). Comparative analysis of PL-treated RJP

revealed pH values spanning from 5.28 ± 0.19 to 5.31 ± 0.13, indicating that the PL treatment did not induce statistically significant alterations in pH ($p > 0.05$). This observation corroborates findings reported by Chakraborty *et al*. (2022) in PL-treated mixed fruit beverages, where no appreciable impact on pH was observed post-treatment. Analogous conclusions were drawn by Teja *et al*. (2017) in UV-C-treated pineapple and apple juice, wherein negligible fluctuations in pH levels were documented. Similarly, Kwaw *et al*. (2018) reported non-significant variations in pH, TA, and TSS in PL-treated lactic acid-fermented mulberry juice.

The PL treatment yielded TA values within the range of 0.53 ± 0.02% to 0.55 ± 0.02%, as illustrated in Table 4.15. Notably, elevated TA values were observed at 2 kV under 200 and 125 pulse conditions. The statistical analysis elucidated that the applied voltage, pulse number, and vertical distance from the PL lamp to the sample did not exert a statistically significant influence ($p > 0.05$) on TA, suggesting that variations in these parameters did not induce substantial modifications in TA levels. These findings align with those of Shaik and Chakraborty (2022), who reported no significant alterations in the pH and TA of sweet lime juice following PL processing at 3 kJ/cm².

TSS levels in both fresh and PL-treated RJP were systematically assessed. The TSS values of the treated samples ranged from 23.70 ± 0.85 to 24.50 ± 0.64°Brix. In congruence with pH and TA findings, TSS exhibited no statistically significant modifications ($p > 0.05$) in response to treatment parameters, including applied voltage, pulse number, and vertical distance from the PL lamp to the sample. However, the highest TSS value (24.50 ± 0.64°Brix) was recorded in samples positioned closest to the lamp under applied voltages of 1.5 kV and 2 kV with corresponding pulse numbers of 200 and 125. This increase in TSS may be attributed to water loss via evaporation, consequently leading to a concentration effect. Comparable outcomes were reported by Palgan *et al*. (2011) in high-intensity PL-treated apple juice, orange juice, and milk. The results derived from the statistical confirmed that process parameters did not significantly influence ($p > 0.05$) the TSS of PL-processed RJP. Table 4.15, presented below, delineates the variations in these physicochemical parameters across different PL treatment conditions

4.6.1.2 Colour characteristics of PL-processed RJP

The untreated RJP exhibited a colorimetric profile characterized by L* = 58.69 ± 1.55, a* = 7.63 ± 0.20, and b* = 57.45 ± 2.50. The chromatic attributes of PL-processed RJP were meticulously assessed, with recorded values ranging from L* = 55.15 ± 1.42 to 56.47 ± 2.02, a* = 7.12 ± 0.31 to 9.04 ± 0.41, and b* = 56.18 ± 2.59 to 58.05 ± 1.53 (Table 4.16). As demonstrated in Table 4.16, subtle variations were observed in the color parameters (L*, a*, b*) of PL-treated RJP compared to the untreated control. The L* parameter, indicative of sample luminosity, decreased from 58.69 ± 1.55 to 55.15 ± 1.42 upon processing under intensified conditions (2.5 kV and 200 pulses) at a lamp-to-sample distance of 7 cm. The reduction in L* was statistically insignificant ($P > 0.05$), suggesting a perceptible darkening effect due to PL treatment. Furthermore, diminishing the lamp-to-sample distance was associated with a further decline in lightness.

Post-PL processing, a* values exhibited a minor increase, signifying a shift towards a redder hue; however, the increment remained statistically non-significant ($P > 0.05$). The most pronounced a* value (9.04 ± 0.41) was observed at 2 kV/200 pulses/4 cm lamp-to-sample distance. Likewise, the marginal increase in b* values was deemed statistically insignificant ($P > 0.05$). The maximum b* value (58.12 ± 1.53) was recorded under 2.5 kV/200 pulses at a 7 cm proximity to the lamp, indicating that PL-treated RJP exhibited a darker visual appearance due to elevated b* values. The observed variations in L*, a*, and b* values may be attributed to the photo-oxidative degradation of colour pigments within RJP during PL exposure (Chakraborty *et al*., 2020). Chia *et al*. (2012) postulated that non-enzymatic Maillard browning, exacerbated by high voltage and pulse intensity, may have contributed to the observed outcome. Comparable findings were reported by Donsingha and Assatarakul (2018), who noted a significant rise in a* values in UV-treated coconut water. Such variations can be ascribed to disparities in sample composition and processing methodologies. The perceptible alterations in yellowness and greenness may stem from pigment decomposition or isomerization, particularly of carotenoids and chlorophyll, as well as the genesis of dark-coloured compounds, potentially induced via photooxidation (Guerrero-Beltran and Barbosa-Cénovas, 2006).

The calculated ΔE values for PL-treated RJP spanned from 2.44 ± 0.11 to 3.59 ± 0.13. The control samples exhibited BI and YI values of 119.87 ± 3.17 and 139.84 ± 6.10, respectively. After PL treatment, BI values fluctuated between 122.88 ± 3.25 and 129.47 ± 5.69, while YI ranged from 142.89 ± 5.15 to 149.51 ± 3.98. The most pronounced ΔE value (3.59 ± 0.13) was registered under 2.5 kV, 200 pulses, and a 7 cm lamp-to-sample distance, conditions that also corresponded with the peak BI of 149.51 ± 3.98. The increased b* value at 2.5 kV/200 pulses accounted for the maximal YI observed under this treatment. Relative to the control, the augmented YI values signified an increase in BI, typically associated with the photodegradation of pigments, notably carotenoids and anthocyanins—although their presence in PL-treated RJP remains relatively limited. According to Cserhalmi *et al*. (2006), perceptible colour differences are classified as "noticeable" (ΔE = 1.5–3.0), "well visible" (ΔE = 3.0–6.0), and "significant" (ΔE = 6.0–12.0). Except for the most intense PL treatment, all PL-exposed samples exhibited a "noticeable" colour change, while the 2.5 kV/200 pulse treatment resulted in a "well visible" alteration (ΔE = 3.6). Elevated PL doses yielded more discernible colour transformations, particularly in conditions involving reduced lamp distances and higher pulse intensities, wherein the impact on chromatic attributes was more pronounced relative to alternative processing configurations (Teja *et al*., 2017).

Table 4.15 Effect of PL on pH, TA and TSS of RJP

Treatment	Voltage (kV)	Pulse number	Distance (cm)	pH	TSS (˚Brix)	TA (%)
PL1	1.5	50	7	5.30±0.23	24.40±0.14	0.54±0.02
PL2	2.5	50	7	5.31±0.24	24.00±1.0	0.55±0.02
PL3	1.5	200	7	5.29±0.13	24.40±0.28	0.54±0.01
PL4	2.5	200	7	5.28±0.19	23.90±0.63	0.55±0.02
PL5	1.5	125	4	5.29±0.19	24.50±0.64	0.54±0.12
PL6	2.5	125	4	5.31±0.13	24.40±1.12	0.55±0.15
PL7	1.5	125	10	5.29±0.24	23.70±0.85	0.54±0.24
PL8	2.5	125	10	5.29±0.19	23.90±0.63	0.55±0.02
PL9	2	50	4	5.30±0.14	23.90±1.29	0.54±0.01
PL10	2	200	4	5.29±0.19	24.50±0.64	0.54±0.12
PL11	2	50	10	5.30±0.23	24.40±0.14	0.53±0.02
PL12	2	200	10	5.29±0.19	23.90±0.63	0.55±0.02
PL13	2	125	7	5.29±0.18	23.80±0.85	0.55±0.20
PL14	2	125	7	5.31±0.19	23.90±0.63	0.54±0.18
PL15	2	125	7	5.31±0.14	24.00±1.04	0.54±0.03
PL16	2	125	7	5.31±0.23	24.30±0.84	0.55±0.02
PL17	2	125	7	5.31±0.24	24.40±1.11	0.54±0.02

Where,TSS-Total soluble solids, TA-Titrable acidity; values are expressed in mean ±SD

Table 4.16 Colour characteristics of PL-processed ripe jackfru

Treatment	L*	a*	b*	ΔE	BI
PL1	55.94±1.52	7.42±0.32	56.35±1.95	2.97±0.13	123.68
PL2	55.88±2.03	7.68±0.27	56.35±2.58	3.02±0.10	123.92
PL3	56.47±2.02	7.95±0.36	56.48±2.05	2.44±0.11	122.88
PL4	55.15±1.42	7.95±0.29	58.12±1.53	3.61±0.13	130.55
PL5	55.79±2.48	7.32±0.19	56.30±2.03	3.13±0.08	123.89
PL6	55.62±2.48	8.05±0.31	58.00±2.08	3.14±0.11	128.92
PL7	55.63±2.63	8.56±0.31	57.65±1.50	3.20±0.12	128.16
PL8	55.54±1.98	8.52±0.23	57.38±2.49	3.27±0.09	127.69
PL9	56.12±1.51	7.12±0.31	56.27±2.59	2.87±0.13	122.93
PL10	56.21±2.44	9.04±0.41	58.05±2.66	2.91±0.13	127.78
PL11	56.00±2.01	7.99±0.37	56.52±2.03	2.87±0.13	124.15
PL12	56.01±2.56	8.46±0.31	57.18±1.53	2.82±0.10	125.91
PL13	56.42±2.02	8.64±0.23	56.71±2.50	2.59±0.07	123.80
PL14	56.15±1.46	8.55±0.37	56.72±1.98	2.96±0.13	123.25
PL15	56.06±1.98	8.64±0.30	56.68±2.62	3.09±0.11	123.42
PL16	56.12±2.02	7.42±0.34	56.42±2.07	2.77±0.13	123.40
PL17	55.22±1.46	8.58±0.31	57.38±1.52	3.60±0.13	128.59

Where, BI: Browning index, YI: Yellowness index; values are expressed in r

4.6.1.3 Effect of PL on the AA content

The untreated RJP reported an AA value of 16.85±0.45 mg/100g. The average AA of PL processed RJP ranged from 13.98±0.50 to 16.62±0.73. The AA retention in the PL processed ripe jackfruit is depicted in Fig 4.67 and shows a significant decline with voltage, pulse number and lamp to sample distance. Elevating the dose level to 2.5 kV/200 flashes led to a statistically significant decline in AA ($P \leq 0.05$). At this increased dose level, with a minimum distance of 7cm from the lamp, the AA content decreased from 16.74±0.73 to 13.98±0.50 mg/100g (Fig 4.68 a, b & c). This indicates that higher voltage doses, increased flashes, and reducing the distance between the lamp and the sample during treatment resulted in a significant reduction in the AA content in the RJP. There was a maximum reduction of 17% in AA reported in RJP at this condition. Chakraborty *et al*. (2014) reported that, as pulses and voltage levels increased during PL treatments, the extent of AA degradation increased as well.

The degradation of AA significantly contributes to non-enzymatic browning reactions in fruit juices. PL treatment can lead to variable AA loss in juices, with higher voltages potentially causing more significant losses due to a phenomenon known as a spectrum shift also known as blue shift or hypsochromic (Dhar and Chakraborty., 2023). The research conducted by Bhagat and Chakraborty (2022) provided strong evidence that higher voltages corresponded to greater depletion of AA.

The statistical analysis demonstrated that voltage, pulse number, and lamp-to-sample distance were significant model terms. Additionally, the interaction effects between voltage and lamp-to-sample distance, as well as between pulse number and lamp-to-sample distance, were also significant. The R^2 value indicates that approximately 98.99% of the variability in the data can be explained by the model. The adjusted R^2 value, which adjusts for the number of predictors in the model, suggests that about 97.69% of the variability is explained while considering the complexity of the model. The predicted R^2 value of 0.93 is reasonably close to the adjusted R^2 value of 0.98. This suggests that the model is performing well in predicting new observations, as the predicted R^2 is not substantially lower than the adjusted R^2. Additionally, the

adequate precision value of 27.51 indicates that the signal-to-noise ratio is sufficiently high, which implies that the model can be used to make reliable predictions (Table D2). The final regression equation for AA in terms of coded factors is given below:

$$AA\ (mg/100g) = 14.91 - 0.95V - 0.38P + 0.33D - 0.063VP - 0.18VD - 0.30PD + 0.047V^2 + 0.46P^2 + 0.20D^2 \quad \ldots. (4.72)$$

Where, V: Voltage (V), P: Number of Pulses, D: lamp to sample distance (cm)

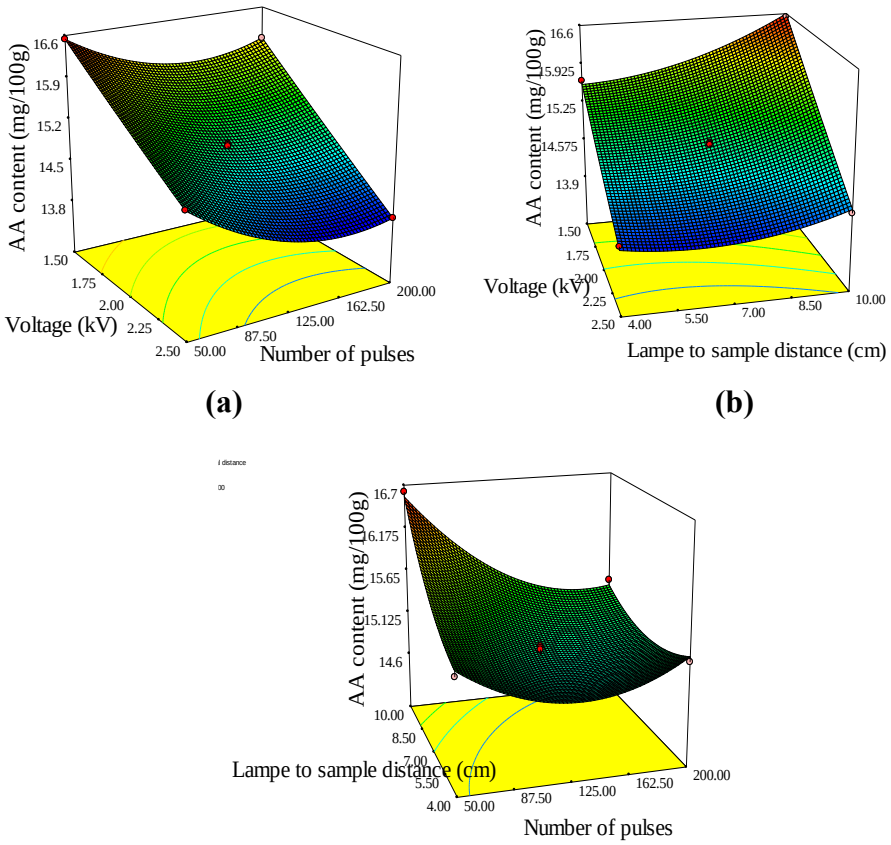


Fig.4.68 AA content of PL treated RJP

4.6.1.4 Effect of PL on the TPC and TFC of PL treated RJP

The fresh RJP exhibited a TPC of 65.14 ± 2.89 mg GAE/g and a TFC of 20.54 ± 0.53 mg RE/g. The treatment process resulted in a TPC range of 62.45 ± 1.65 to 66.10

± 2.87 mg GAE/g (Fig. 4.69 .69a, b & c), while TFC varied between 17.58 ± 0.77 and 21.12 ± 0.71 mg RE/g (Fig. 4 .70a, b & c) across all PL treatment conditions. The application of PL treatment either preserved or slightly enhanced TPC and TFC at lower dosages. However, a statistically significant decline ($P > 0.05$) was observed at higher intensities. Specifically, an increase of 1.58% in TPC was noted at 2 kV/200 pulses/4 cm lamp-to-sample distance, while TFC exhibited a 2.74% enhancement under identical conditions. Conversely, at 2.5 kV/200 pulses/7 cm, TPC and TFC demonstrated a maximum reduction of 4.14% and 14.4%, respectively.

Statistical analysis via ANOVA for the response surface quadratic model further validated these observations. The ANOVA results for TPC demonstrated a highly significant model ($P = 0.0002$), with voltage (A) ($P < 0.0001$), voltage-pulse number interaction ($P = 0.004$), and voltage squared ($P < 0.0001$) emerging as significant model terms (Table D3). The model exhibited an R-squared value of 0.97, with an adjusted R-squared of 0.93 and a predicted R-squared of 0.86, indicating a robust predictive capacity. The adequate precision of 15.14 further affirmed the model's reliability in navigating the design space. The lack of fit ($P = 0.80$) was non-significant, reinforcing the validity of the model.

For TFC, ANOVA results also indicated a significant model ($P < 0.0001$). Voltage (A) ($P < 0.0001$), vertical distance (C) ($P = 0.0095$), voltage-pulse number interaction (AB) ($P = 0.0002$), and pulse number-vertical distance interaction (BC) ($P = 0.0172$) were identified as significant contributors. The model's R^2 value stood at 0.9765, with an adjusted R^2 of 0.9463 and a predicted R^2 of 0.8406, suggesting a high degree of model accuracy (Table D4). The adequate precision value of 19.386 confirmed a strong signal-to-noise ratio, reinforcing the model's predictive capability. The lack of fit remained non-significant ($P = 0.5745$), ensuring the model's suitability for further application.

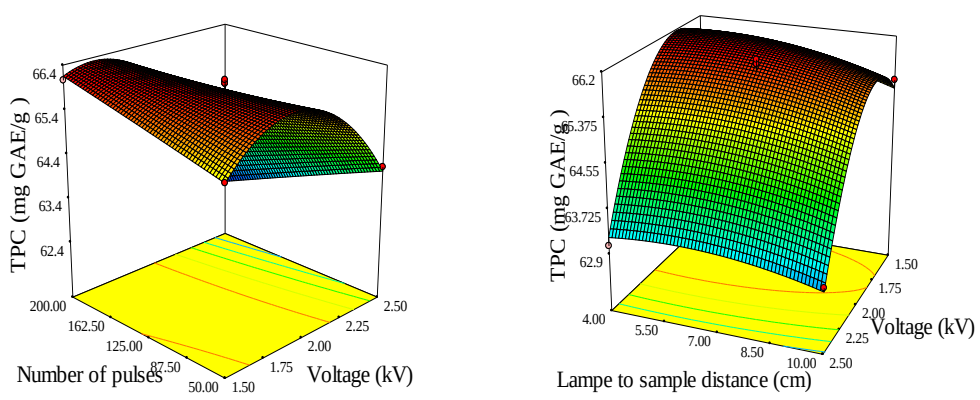
Previous literature corroborates these findings. Valdivia-Nájar *et al*. (2018) reported an increase in TPC in PL-treated tomato slices, while Agüero *et al*. (2016) noted enhanced phenolic and antioxidant activity in PL-treated spinach. Teja *et al*. (2017) documented a maximum reduction of 8% in TPC in PL-treated pineapple juice, aligning with the trends observed in the present study.

The preservation of bioactive compounds in RJP is attributed to the presence of complex protective compounds that mitigate oxidation processes, thermal degradation, and photodecomposition. These compounds act as natural safeguards against PL-induced degradation (Basak *et al*., 2022). Additionally, multiple studies have demonstrated that PL exposure stimulates phenolic biosynthesis via stress-response activation. However, certain investigations have reported negligible changes or negative effects at elevated PL intensities and prolonged pulse durations. Pataro *et al*. (2015) and Vargas-Ramella *et al*. (2021) posited that PL, being a surface treatment, potentially shields polyphenols, which are predominantly sequestered in vacuoles, thereby minimizing their degradation. The present study supports these findings, reinforcing the potential of PL treatment as a non-thermal technology for preserving the phenolic and flavonoid integrity of RJP.

$$\text{TPC (mg GAE/g)} = 65.86-1.20V-0.14P-0.21D-0.65\,VP+0.070\,VD-0.21P\,D1.40V^2-0.011P^2-0.19D^2 \quad \ldots (4.73)$$

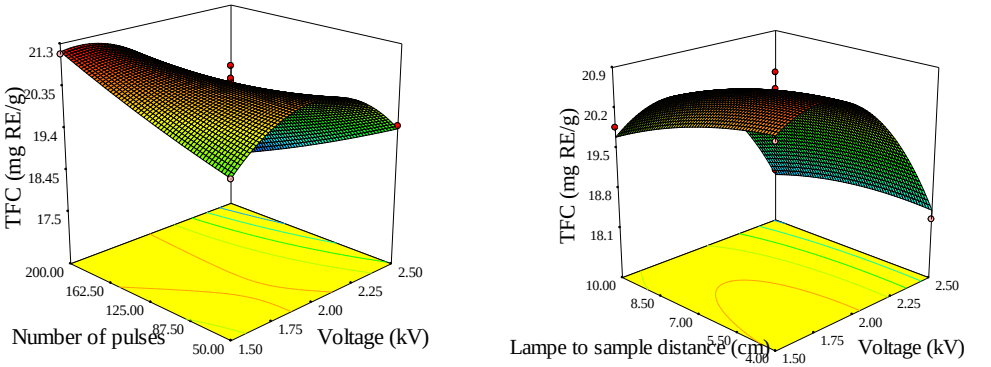
$$\text{TFC (mg RE/g)} =20.46-0.95V-0.094P-0.30D-0.84VP+0.14PD-0.37PD-1.10V^2+0.080P^2-0.15D^2 \quad \ldots (4.74)$$

Where, V: Voltage (V), P: Number of Pulses, D: lamp to sample distance (cm)



(a) **(b)**

Fig 4.69 Effect of PL on the TPC of PL treated RJP



(a) **(b)**

Fig 4.70 Effect of PL on the TFC of PL treated RJP

4.6.1.5 Effect of PL on the total sugar content

The total sugar concentration in the untreated RJP was initially recorded at 22.42 ± 0.98%. Following PL treatment, a slight increase in total sugar content was observed, ranging from 22.41 ± 1.03% to a maximum of 22.65%. However, this increase was determined to be statistically insignificant ($p>0.05$). Notably, the highest total sugar content was recorded at a PL treatment intensity of 1.5 kV with 125 pulses at a 10 cm lamp-to-sample distance. These findings are consistent with the observations reported by Ashitha and Prince (2020), who investigated the effect of PL treatment on pineapple and cashew apple juices under varying process conditions (PL dosage: 8-32 J/cm², sample source distance: 5-15 cm, and flow rate: 150-300 mL/min), concluding that no significant alterations were induced in the total sugar content of the treated samples.

The observed increment in total reducing sugars in bael fruit juice post-PL treatment has been attributed to enhanced extraction mechanisms, facilitated either by the liberation of sugars from the food matrix or through hydrolytic degradation processes (Dhar and Chakraborty, 2023). Similarly, Aguiló-Aguayo *et al*. (2015) documented a 19% increase in fructose at a PL dosage of 5.41 J/cm² and a 5.7% enhancement in β-glucose following a 2.26 J/cm² PL exposure in carrot slices. The variability in total sugar content observed across different PL process conditions applied to RJP is systematically presented in Table 4.3.

Statistical analysis of the data indicates the absence of significant model terms, as evidenced by "Prob > F" values exceeding the threshold of 0.1000. Moreover, the Lack of Fit F-value was calculated to be 1.23, signifying that the lack of fit is not statistically significant when compared to the pure error component. The probability of obtaining a Lack of Fit F-value of this magnitude purely due to noise was estimated at 45.99%. These statistical findings reinforce the conclusion that while PL treatment induces slight modifications in total sugar content, these alterations are not statistically significant and likely result from minor biochemical or physicochemical changes induced by PL exposure.

4.6.1.6 Effect of PL on the DPPH radical scavenging activity

The DPPH radical scavenging activity of fresh RJP was determined to be 84.32 ± 3.68%. Upon PL treatment, the DPPH radical scavenging activity exhibited a range between 83.15 ± 3.81% and 84.78 ± 2.94%, with the majority of treatment conditions leading to either full retention or a slight enhancement of DPPH radical scavenging activity. Notably, a maximal increase in DPPH radical scavenging activity was recorded at 1.5 kV/125 pulses/4 cm, whereas the most intense treatment at 2.5 kV resulted in a 1.40% reduction. These variations highlight the nuanced effects of PL treatment on antioxidant activity, with more severe intensities inducing minor degradative impacts.

A similar trend has been observed in PL-treated Amla juice, where Chakraborty *et al*. (2020) reported a peak increase of 4% at 2.8 kV/5 min, contrasted with a 3% decline at 2.9 kV/3 min. Additionally, Vollmer *et al*. (2020) demonstrated that PL treatments ranging from 160 to 375 J/cm² had no statistically significant impact on the antioxidant capacity of pineapple juice. The enhancement in antioxidant properties is potentially attributed to the activation of phenylalanine ammonia-lyase, which plays a crucial role in phenolic biosynthesis. Furthermore, light-induced modifications in the structural conformation of phenolic compounds, particularly benzoic ring transformations, coupled with the thermal effects of infrared radiation, may contribute to the observed variations in antioxidant efficacy, especially under more intense PL conditions (Chakraborty *et al*., 2020).

Comparative studies by Basak *et al*. (2022) evaluated the efficacy of PL treatment (3000 J/cm²) versus conventional thermal processing (90 °C for 5 minutes) on a mixed juice comprising apple bear, carambola, and black table grape. Their findings indicated a 12.8% reduction in antioxidant capacity following PL exposure, reinforcing the hypothesis that higher PL dosages may induce oxidative degradation in bioactive components.

The statistical analysis using three-way ANOVA revealed that the process parameters had no statistically significant effect ($p > 0.05$) on the DPPH radical scavenging activity of PL-processed RJP. The variations in antioxidant capacity under different PL treatment conditions are summarized in Table 4.17, underscoring the

complex interplay between PL intensity, exposure duration, and sample positioning in modulating the oxidative stability of bioactive compounds.

Table 4.17 Effect of PL on Total sugar and DPPH radical scavenging activity of RJP

Treatment	Total Sugar Content (%)	DPPH Scavenging activity
PL1	22.48±0.78	84.78±2.94
PL2	22.54±1.03	83.15±3.81
PL3	22.45±0.81	84.66±3.05
PL4	22.55±0.60	84.46±2.23
PL5	22.43±0.81	84.75±3.06
PL6	22.47±0.81	83.53±3.01
PL7	22.65±0.60	84.72±2.24
PL8	22.55±0.98	84.73±3.69
PL9	22.44±1.03	84.67±3.88
PL10	22.41±1.03	84.64±3.88
PL11	22.46±0.81	84.61±3.05
PL12	22.45±0.59	84.59±2.24
PL13	22.44±0.98	84.65±3.69
PL14	22.41±0.78	84.61±2.93
PL15	22.43±1.03	84.63±3.88
PL16	22.53±0.81	83.95±3.03
PL17	22.54±0.60	84.62±2.24

Values are expressed in mean ±SD

4.6.1.7 The rheological properties of PL processed jackfruit pulp

The viscosity of untreated (control) RJP was 61.89 ± 1.12 Pa.s. Following PL treatment, viscosity values ranged from 55.14 ± 1.02 Pa.s to 61.12 ± 0.15 Pa.s, (Fig 4.71), depending on the applied pulse number, lamp-to-sample vertical distance, and

voltage level. The results indicate a general reduction in viscosity with increasing pulse number, shorter vertical distances, and higher voltages.

At a constant voltage of 1.5 kV and vertical distance of 7 cm, increasing the pulse number from 50 to 200 led to a progressive decrease in viscosity from 61.12 ± 0.15 Pa.s to 58.47 ± 0.87 Pa.s. A similar pattern was observed at 2 kV, where viscosity decreased from 58.87 ± 0.76 Pa.s to 57.26 ± 0.81 Pa.s at 125 pulses. This trend suggests that higher pulse numbers facilitate greater structural degradation of the pulp matrix, leading to increased intracellular fluid release and reduced resistance to flow.

The effect of vertical distance was also evident, as reducing the distance from 10 cm to 4 cm at a pulse number of 125 and 1.5 kV resulted in a viscosity drop from 59.26 ± 0.88 Pa.s to 55.14 ± 1.02 Pa.s. This indicates that a shorter lamp-to-sample distance increases light intensity, leading to enhanced modification of pulp structure and a more fluid consistency. However, at shorter distances, the pulp generally displayed higher viscosities, suggesting that closer light exposure induced more structural changes in the pulp matrix (Bhavya and Hebbar, 2017).

Voltage played a role in further reducing viscosity, although its effect was dependent on the pulse number and vertical distance. At a fixed pulse number of 125 and vertical distance of 7 cm, increasing the voltage from 1.5 kV to 2 kV resulted in a viscosity change from 55.72 ± 0.77 Pa.s to 58.87 ± 0.76 Pa.s, respectively. Higher voltage resulted in a slight reduction in the internal structural resistance of the pulp, leading to a lower viscosity (Mandal *et al.,* 2020). While this suggests that higher voltage levels can facilitate structural breakdown, the impact appears to be more pronounced when combined with shorter distances and increased pulse numbers.

Compared to the control (61.89 Pa.s), most PL-treated samples exhibited a reduction in viscosity, with the highest decrease observed at 1.5 kV, 125 pulses, and 4 cm (55.14 ± 1.02 Pa.s), representing a 10.9% reduction. This suggests that higher energy exposure from a shorter distance and moderate pulse numbers maximizes viscosity reduction. The results demonstrate that pulsed light treatment significantly influences the rheological properties of ripe jackfruit pulp, which can be beneficial for processing applications requiring lower viscosity.

The jackfruit pulp consistently exhibited shear-thinning behavior, where its viscosity decreased as the shear rate increased, a hallmark of non-Newtonian fluids. This was evident across all processing conditions. For example, at 2kv and 125 pulses, reducing the shear rate from 1.609 s^{-1} to 1.094 s^{-1} (as the distance decreased) led to an increase in viscosity from 55.65 Pa·s to 62.12 Pa·s. The behavior supports the conclusion that the pulp becomes less viscous as the applied stress increases, making it easier to process.

Fig 4.72 depicts the relationship between shear rate (1/s) and viscosity (Pa.s) for PL-treated jackfruit pulp, along with the control sample. The data shows a clear shear-thinning behavior, where viscosity decreases as shear rate increases. This trend is typical for non-Newtonian fluids, particularly pseudoplastic fluids, where structural breakdown under shear stress leads to reduced viscosity. The power-law model parameters for the control and PL-treated jackfruit pulp were Control: k=255.42, n = 0.61 and PL-Treated: k=268.25, n=0.57. Since n < 1, both control and PL-treated pulp exhibit shear-thinning behavior. However, the PL-treated pulp has a slightly lower flow behavior index (n = 0.57), indicating an enhanced shear-thinning effect, likely due to structural modifications caused by pulsed light exposure. The lower viscosity at higher shear rates further confirms the effect of PL treatment on reducing the internal structural resistance of the pulp

The Analysis of Variance (ANOVA) Table D7 evaluates the significance of voltage (A), pulse number (B), and vertical distance (C) on the viscosity of pulsed-light-treated jackfruit pulp. The overall model is significant (p = 0.0051, F = 6.89 and R^2 = 0.61), meaning that at least one of the factors (A, B, or C) has a statistically significant effect on viscosity. The regression equation for the viscosity is given below

Viscosity= 57.77-1.30 V-1.01 P+1.19D …(4.75)

Where, V: Voltage (V), P: Number of Pulses, D: lamp to sample distance (cm)

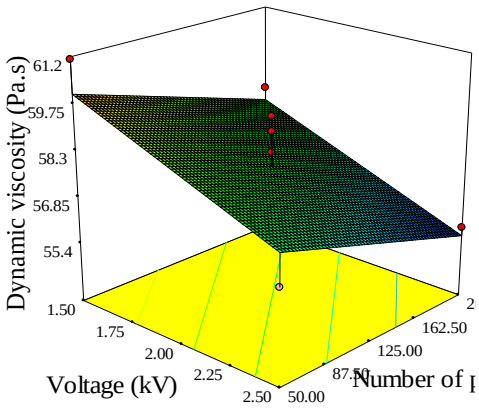


Fig.4.71 Viscosity of PL treated RJP

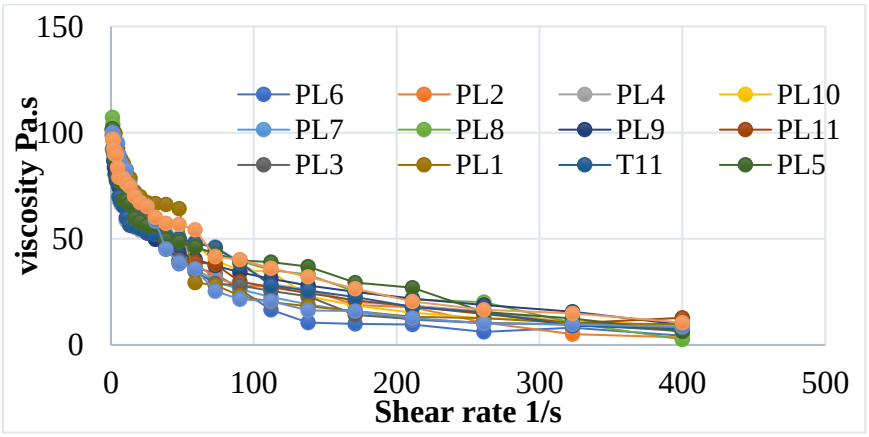


Fig.4.72 Viscosity of PL processed RJP as a function of shear rate

4.6.1.8 Effect of PL on microbial reduction

The study examined the microbial activity of PL processed RJP under various conditions of voltage, pulse number, and vertical distance. The control sample exhibited an initial population of 4.2 log CFU/g. The results revealed that an increase in voltage and pulse number generally led to a significant reduction in both TAM and yeast/mold counts. For TAM, the counts ranged from 1.04 to 6.68 log CFU/g (Fig 4.73). At 1.5 V and 50 pulses, the TAM count was reduced to 1.88 log CFU/g, while at 2.5 V and 200 pulses, the count was reduced to 6.68 log CFU/g. For yeast/mold, the counts ranged from 0.64 to 6.3 log CFU/g (Fig 4.74). At 1.5 V and 50 pulses, the yeast/mold count was 0.95 log CFU/g, and at 2.5 V and 200 pulses, the count was 6.3 log CFU/g. The results revealed that an increase in voltage and pulse number generally led to a significant reduction in both TAM and yeast/mold counts. For instance, at 1.5 V and 50

pulses, the TAM count was reduced to 1.88 log CFU/g and yeast/mold to 0.95 log CFU/g. At 2.5 V and 200 pulses, the reduction was more pronounced, with counts dropping to 6.68 log CFU/g for TAM and 6.3 log CFU/g for yeast/mold. Vertical distance also influenced the microbial reduction, with a distance of 10 cm generally showing lower microbial counts compared to shorter distances. For example, at 2 V, 50 pulses, and a 10 cm distance, the TAM count was 2.2 log cfu/g and yeast/mold were 1.9 log CFU/g. These findings suggest that higher voltages and pulse numbers, along with optimal vertical distances, enhance the effectiveness of PL treatment in reducing microbial populations in RJP. Preetha *et al*. (2016) demonstrated a maximum *E. coli* inactivation of 6.3 log CFU/ml under similar conditions.

The combined photochemical, photothermal, and photophysical mechanisms of PL result in efficient microbial reduction. Prolonged PL exposure can cause immediate microbial cell collapse (Ferrario *et al*., 2014). Increased PL intensity and pulse numbers improve inactivation and reduce the likelihood of photoreactivation. This comprehensive approach explains the enhanced microbial reduction observed in RJP treated with PL. In the study, Vollmer *et al*. 2020 demonstrated that PL treatment of pineapple juice significantly reduces microbial populations. Specifically, a treatment at 2.4 kV with 94 pulses achieved a 5-log cycle reduction in both aerobic mesophiles and yeast and mold counts. Furthermore, increasing the treatment to 2.4 kV with 187 pulses resulted in microbial levels dropping below detection limits.

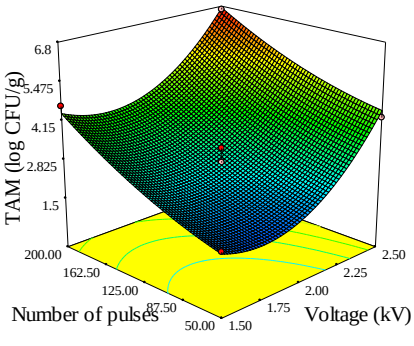
The ANOVA table for the reduction of TAM reveals significant insights into the effectiveness of the applied model. The overall model is statistically significant, indicated by an F-value of 36.04 and a p-value of less than 0.0001, suggesting a mere 0.01% likelihood that such a large F-value could arise from random noise. Significant factors influencing bacterial reduction include voltage V), pulse number (P), vertical distance (D), and the interaction terms VD and PD, along with the quadratic terms V^2 and D^2, all exhibiting p-values below 0.05. Conversely, the interaction term VP and the quadratic term B^2 are not significant, as indicated by their higher p-values. The lack of fit is also non-significant, with an F-value of 2.73 and a p-value of 0.1782, suggesting that the model adequately fits the data without substantial deviations.

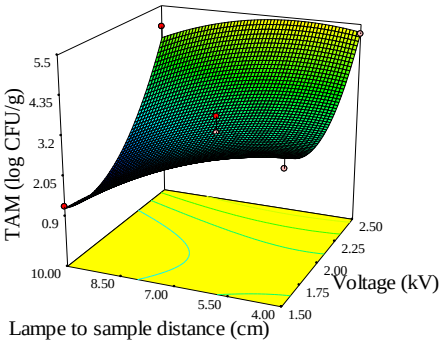
The ANOVA results for the reduction in TAM and yeast and mold both demonstrate significant models with high F-values (36.04 and 63.75, respectively) and low p-values (< 0.0001) for the overall models, indicating their effectiveness in evaluating microbial reduction. Key factors such as voltage, pulse number, and vertical distance, along with relevant interaction and quadratic terms, exhibit p-values below 0.05 in both analyses, highlighting their significant influence on reducing total mesophilic bacteria and yeast and Mold. Both models show high R^2 values, with 0.9789 for TAM and 0.9879 for yeast and mold, suggesting strong correlations between observed and predicted values. The predicted R^2 values are also in reasonable agreement with the adjusted R^2 values for both analyses. However, a notable difference is observed in the lack of fit, which was non-significant for yeast and mold (p-value = 0.0900) but significant for total mesophilic bacteria, suggesting that the yeast and mold model better fits the data without substantial deviations. Overall, both models effectively assess microbial reduction, although the yeast and mold analysis demonstrate a stronger fit with a non-significant lack of fit.

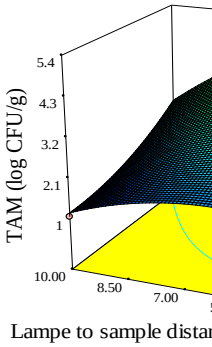
$$TAM = 2.80+1.26V+1.21\ P-0.81D-0.11V\ P+0.42\ VD-0.54P\ D+1.29\ V^2+0.30P^2-0.47\ D^2 \quad \ldots (4.76)$$

$$Yeast/mold=1.86+1.30V+1.23P-0.55D+0.025VP+0.34VD-0.40PD+1.39V^2+0.36P^2-0.34D^2 \quad \ldots(4.77)$$

Where, V: Voltage (V), P: Number of Pulses, D: lamp to sample distance (cm)

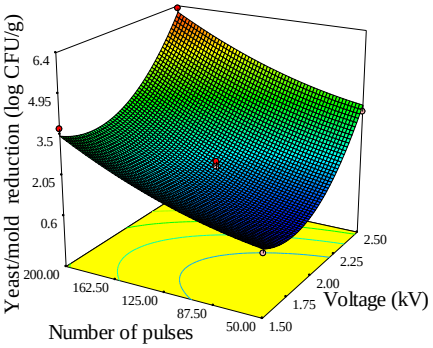


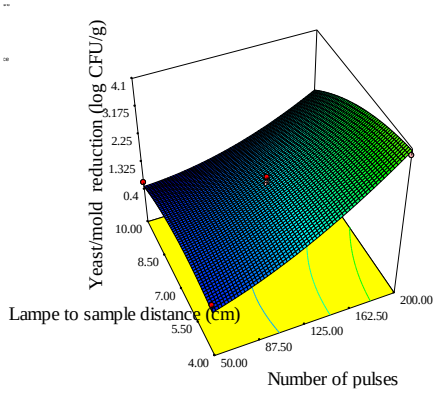


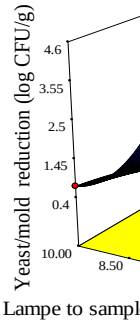


(a) **(b)** **(c)**

Fig 4.73 Effect of PL on the TAM of PL treated RJP







(a) **(b)** **(c)**

Fig 4.74 Effect of PL on the yeast and mold of PL treated RJP

4.6.1.9 Sensory analysis

The control sample exhibited high scores across all sensory attributes, with colour rated at 8.7, aroma at 8.8, taste at 8.6, texture at 8.8, and overall acceptability at 8.7 (Fig 4.75). These scores set a benchmark for evaluating the effects of PL treatments. When PL was applied at a voltage of 1.5 Kv and a pulse number of 50 with a vertical distance of 7 cm (PL1), the scores for colour, aroma, taste, texture, and overall acceptability were 7, 6.8, 6.6, 8.4 and 6.3, respectively. This treatment showed a noticeable decline in sensory scores compared to the control, particularly in taste and overall acceptability. Increasing the pulse number to 200 under the same voltage and vertical distance (PL3) resulted in colour, aroma, taste, texture, and overall acceptability scores of 7.1, 6.8, 6.9, 8.6 and 7.4, respectively. This indicates a slight improvement in sensory attributes compared to PL1, particularly in taste and texture. When the vertical distance was increased to 10 cm, as seen in PL5 and PL7, the sensory scores generally declined further. For instance, PL5 had scores of 7.3 for colour, 6.8 for aroma, 6.5 for taste, 8.7 for texture, and 7.3 for overall acceptability. This suggests that increasing the vertical distance may negatively impact the sensory attributes of the pulp. For treatments involving varying voltages and pulse numbers with a vertical distance of 7 cm (PL9, PL10, PL11, PL12, PL13, PL14, PL15), the sensory scores varied. For example, PL9, with a voltage of 1.15 and a pulse number of 125, showed scores of 7.2 for colour, 7.1 for aroma, 6.6 for taste, 8.3 for texture, and 7.12 for overall acceptability. This treatment had relatively balanced scores across attributes, indicating a moderate level of acceptance. In contrast, PL11, which involved a voltage of 2 kv and a pulse number of 50, resulted in lower scores: 6.4 for colour, 5.9 for aroma, 5.1 for taste, 8.1 for texture, and 5.4 for overall acceptability. This suggests that inappropriate voltage and pulse number combinations can significantly degrade the sensory quality of the pulp. Overall, the data indicate that PL processing can influence the sensory attributes of RJP, with certain parameter combinations yielding better sensory quality than others. Further optimization of these parameters is necessary to enhance the sensory acceptance of PL processed jackfruit pulp.

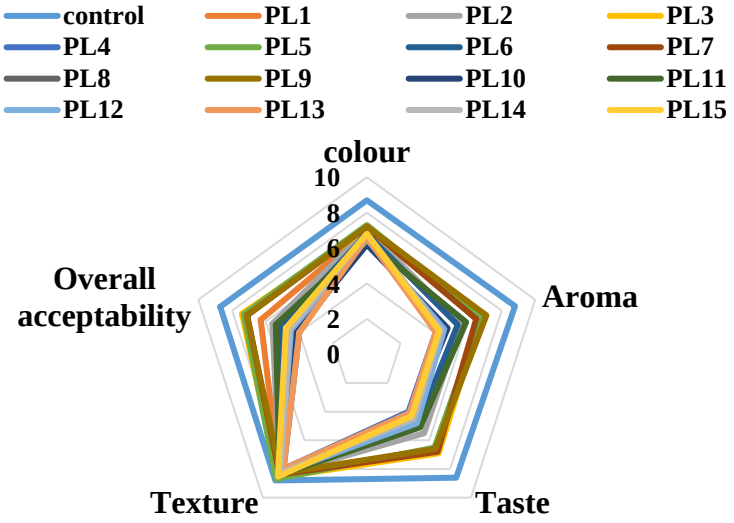


Fig.4.75 Sensory analysis of PL treated RJP

4.6.2 Numerical optimization

The optimization of PL processed RJP utilized a statistical model to balance multiple response variables: AA, TPC, TFC, reduction in microbial load, and yeast/mold count. The constraints were voltage (1.5 to 2.5 kV), pulse number (50 to 200 pulses), and vertical distance (4 to 10 cm). The goal was to maximize AA (13.98 to 16.62 mg/100 g), TPC (62.45 to 66.1 mg GAE/100g), TFC (17.58 to 21.12 mg RE/100 g), TAM (1.04 to 6.68 log CFU/g), and yeast/mold count (0.64 to 6.3 log CFU/g). The optimal solution, as determined by the desirability function, involved using a voltage of 1.50 kV, 200 pulses, and a vertical distance of 4.00 cm. This configuration resulted in AA of 16.067 mg/100 g, TPC of 66.459 mg GAE/100 g, TFC of 21.793 mg RE/100 g, a microbial reduction of 5.735 log CFU/g, and a yeast/mold count of 4.449 log CFU/g. The desirability score of 0.850 indicated the optimal balance across all variables, making this the selected process condition.

4.6.3 Cost analysis

The cost analysis for pulsed light-treated ripe jackfruit pulp was conducted based on the assumption of producing 2000 bottles (each containing 500 ml) annually. The cost per bottle for processing was calculated to be ₹778. Additionally, the cost of the

pulp and packaging was included, amounting to ₹62.5 for the pulp and ₹5 for packaging, bringing the total cost per bottle to ₹778 (Appendix G5). However, these cost estimations are based on processing carried out using a lab-scale PL machine with limited capacity, which significantly inflates the production cost and makes the benefit-cost ratio (BCR) calculation impractical for commercial comparison. A commercial-scale PL system with higher throughput could substantially reduce the per-unit cost and improve economic feasibility.

4.7 Effect of storage on PL processed RJP

PL processing was optimised prior to storage to establish the shelf life of the selected sample. The sample treated at 1.5 kV, with 200 pulses, and a lamp-to-sample distance of 4 cm, was identified as the best treatment based on quality analysis, sensory evaluation, and statistical results. The optimised sample was then stored under refrigerated conditions, with quality assessments conducted at 10-day intervals. The effect of storage on physicochemical parameters is discussed below.

4.7.1 Effect of storage on pH, Titratable acidity, and TSS of PL processed RJP

The study investigated the effects of PL treatment on the quality parameters of RJP under refrigerated storage over 35 days. The initial pH value of the fresh pulp was recorded at 5.31 ± 0.21, which decreased to 5.00 ± 0.19 by the 10^{th} day, and eventually, PL treated sample fluctuated between 5.27 ± 0.27 to 5.30 ± 0.20 after 35 days (Fig 4.76). The TA of the fresh pulp was initially 0.54 ± 0.02%, which increased slightly to 0.60±0.05% after 10 days, then ranged from 0.55 ± 0.04% to 0.58 ± 0.05% for the treated sample during 35th days of storage. The TSS of the fresh pulp was initially measured at 23.80 ± 0.49 °Brix, increasing to 24.10 ± 0.62 °Brix after 10 days and varying slightly from 24.49±0.55 °Brix on the 10th day to 24.59 ± 1.69°Brix on the 35^{th} day for optimised sample. The PL treatment helped maintain the pH, TA, and TSS of RJP during the 35-day refrigerated storage period, with only minor fluctuations observed. The stable pH and TA were likely due to the PL treatment's inhibition of lactic acid bacteria and spoilage microorganisms which prevents the production of acidic metabolites that could lower the pH. Moreover, the stable acidity during storage suggests negligible oxidative reactions, consistent with findings by Kwaw *et al*. (2018) who observed similar effects in PL-treated mulberry juice. In addition, Basak *et al*. (2022) reported that light pulses could not disrupt covalent bonds necessary for decomposition processes that alter pH, TA, and TSS. The hydrolysis of complex sugars into simple sugars facilitated microbial growth utilizing the simple sugars while maintaining pH stability. Chakraborty *et al*. (2020) also noted that the processing temperature, along with infrared and ultraviolet spectra from PL, could not dissociate sugar molecules into soluble fragments in juice.

The ANOVA results for pH indicated no significant differences among the storage days ($p = 1.000$). The homogeneity of variances was confirmed. The post hoc Duncan test further corroborated this by showing homogeneous subsets, with pH values ranging from 5.27 to 5.30 and a significance level of 0.92. For TA, ANOVA showed no significant differences between storage days ($p = 0.95$). The Duncan post hoc test indicated homogeneous subsets across all storage days, with TA values ranging from 0.54% to 0.58% and a significance level of 0.42 TSS levels analyzed using ANOVA also showed no significant differences between groups ($p = 1.000$). The Duncan post hoc test results for TSS demonstrated homogeneous subsets across all storage days, with TSS values remaining stable from 24.49 °Brix to 24.58 °Brix and a significance level of 0.92.

Overall, the study demonstrated that PL treatment effectively maintained the quality of jackfruit pulp during refrigerated storage, as indicated by the stable pH, TA, and TSS values over the 35-day period. This stability reflects the minimal impact of PL treatment on the chemical properties of the jackfruit pulp, aligning with previous studies on different fruit juices.

4.7.2 Effect of storage on ΔE of PL processed RJP

The **ΔE** data for PL treated RJP under refrigerated storage ranged from 2.30 ± 0.70 immediately after processing to 6.15 ± 0.28 on the 35th day (Fig 4.77), indicating a significant effect of storage duration on colour changes ($p < 0.001$).The redness value (a*) decreased for PL treated sample It is worth noting that low browning was observed in PL-treated juices, despite increasing enzyme activity with storage. This indicates non-enzymatic browning is the major mechanism of browning in the juice during storage. While maillard browning is responsible for browning in thermally treated juices, the degradation of AA and polyphenols also can contribute to browning (Hu *et al*., 2023). The high retention of AA and total phenolics in the PL-treated juice further confirms that the low browning in PL-treated juice was due to higher amounts of AA and total phenols, which were retained due to the non-thermal treatment. Donsingha and Assatarakul (2018) also observed changes in a* values when coconut water was treated with UV irradiation, increasing purpleness during storage. At the end of the storage period, ΔE was in the 'noticeable' range for the PL-treated juice

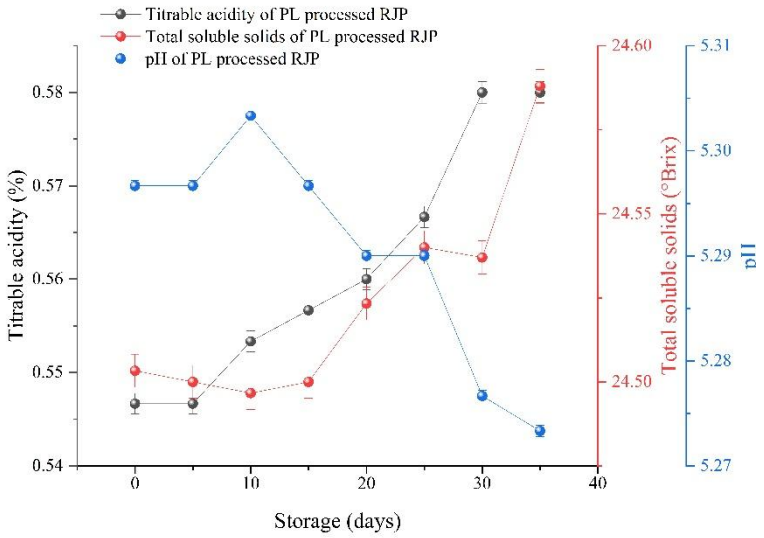


Fig.4.76 Effect of storage on pH, TA, and TSS of PL processed RJP

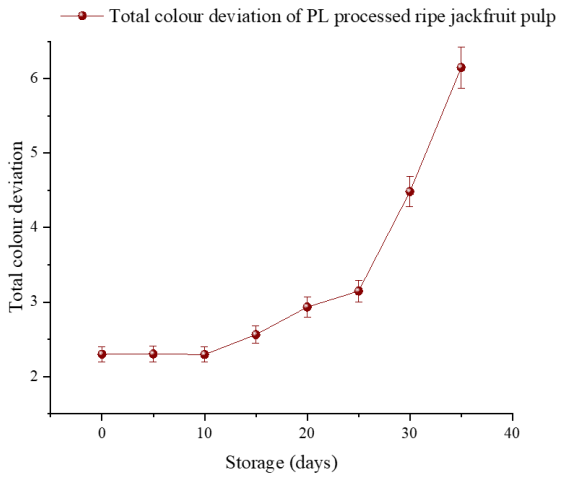


Fig.4.77 Effect of storage on total colour deviation of PL processed RJP

4.7.3 Effect of storage on AA content of PL processed RJP

The AA content in PL processed RJP was analyzed over a refrigerated storage period of 35 days. Initially, the AA content was 16.85 ± 0.01 g/100mg, which decreased to 13 ± 1.23 g/100 mg by the 10th day, indicating a significant reduction. Over the 35-day storage period, the AA content ranged from 16.00 ± 1.05 g/100 mg on the 5th day to 13.57 ±1.13 g/100 mg on the 35th day. The content on the intermediate days was 15.99 ± 1.03 g/100 mg on the 0th day and 14.88 ± 1.12 g/100mg on the 30th day. ANOVA results demonstrated significant differences in AA content between the different storage

intervals (p = 0.041). Post hoc analysis using Duncan's test revealed two homogeneous subsets, indicating a significant reduction in AA content, particularly after the 25th day of storage. Overall, the retention of AA was approximately 80.51% from the initial content to the 35th day, highlighting the impact of storage duration on the nutrient content in PL-treated jackfruit pulp.

In examining the impact of PL treatment on RJP, a notable reduction in antioxidant capacity occurred during storage, despite the treatment's initial efficacy in retaining antioxidants. This decline may be attributed to oxygen diffusion, albeit minimal, which could facilitate aerobic oxidation during refrigerated storage. Additionally, the presence of metal ions and dissolved oxygen concentration in the juice might have catalyzed the aerobic oxidation of AA, leading to its degradation over time (Vollmer *et al*., 2020).

Previous research by Denoya *et al*. (2020) on the quality of persimmons post-PL treatment showed no significant effect on AA during storage, suggesting variations in fruit types and processing methods. Similarly, studies by La-Cava and Sgroppo (2015) on grapefruit juice treated with UV-C light demonstrated a reduction of up to 30% in initial AA levels during refrigerated storage. Moreover, the degradation of AA following PL treatment can be attributed to the formation of ascorbyl radicals during the UV portion of PL, leading to subsequent reactions even in the absence of light. Factors such as pH, metal ion concentration, and the photothermal effect of PL are significant contributors to the oxidation of AA to its keto form (Chakraborty *et al*., 2020).

4.7.4 Effect of storage on TPC of PL processed RJP

The TPC of PL processed RJP, treated at 1.5 kV for 200 pulses with a 4 cm lamp-to-sample distance during 35 days of refrigerated storage, ranged from 66.08 ±0.075 mg GAE/g on the 0th day to 63.41 ± 0.41 mg GAE/g on the 35th day. Initially, the TPC of the fresh pulp was measured at 65.14 ± 0.08 mg GAE/g, which decreased to 13 ± 0.38 mg GAE/g by the 10th day. The ANOVA results revealed a significant difference in TPC across the storage period (p = 0.031). Duncan's multiple range test indicated two homogeneous subsets. The first subset, comprising the TPC from the 35th to the 30th

day, exhibited values ranging from 63.41 ± 0.41 to 64.76 ± 0.58 mg GAE/g. From the 25th to the 0th day, the second subset showed values from 65.12 ± 0.08 to 66.08 ± 0.07 mg GAE/g. These results indicate a notable retention of phenolic content over the storage period. The percentage retention of phenolic compounds from the initial to the final measurement was calculated to be approximately 95.96%, indicating a loss of 4.04%, which highlights the stability of these compounds during the storage period.

Basak *et al*. (2022) observed a significant decrease in TPC during storage of a mixed fruit beverage at refrigerated condition. The loss in TPC was mainly during storage may be due to the negligible antioxidant activity in the pulp during storage.

4.7.5 Effect of storage on Total sugar of PL processed RJP

The total sugar in the PL processed RJP were monitored over a 35-day refrigerated storage period. The initial total sugar value of the fresh pulp was measured at 22.42 ± 0.23%. Over the course of storage, the TSS showed a decrease, reaching a value of 20.12 ± 0.33% by the 10th day (Fig 4.78).

The ANOVA was performed to compare the TSS values across different storage days, yielding an F-value of 0.318 with a significance level of 0.935, indicating no statistically significant differences among the groups.

Post hoc analysis using Duncan's multiple range test identified a single homogeneous subset for alpha = 0.05. The total sugar values across the storage days ranged from 20.88 ± 1.79% on the 35th day to 22.44 ± 0.28% on the 0th day. On specific days, the total sugar values were observed as follows: 21.58 ± 1.42% on the 30th day, 21.66 ± 1.23% on the 25th day, 21.88 ± 1.30% on the 20th day, 21.95 ± 2.01% on the 15th day, 22.41±0.03% on the 5th day, and 22.44 ± 1.50% on the 0th day. The loss percentage of the total sugar over the 35 days ranged from 0.64% to 7.02%.

Overall, the results suggest that the total sugar values of PL processed jackfruit pulp experienced some loss during the 35 days of refrigerated storage, with minor fluctuations that were not statistically significant. The observed variation in sugar content in the treated jackfruit samples can be attributed to the differing levels of surviving microbes. As the storage period progressed, the increase in viable microbes likely caused a more pronounced decline in sugar content. This aligns with findings by

Pandiselvam *et al*. (2020), who reported a significant reduction in total sugar content in microwave-processed coconut inflorescence sap during a 16-day storage period.

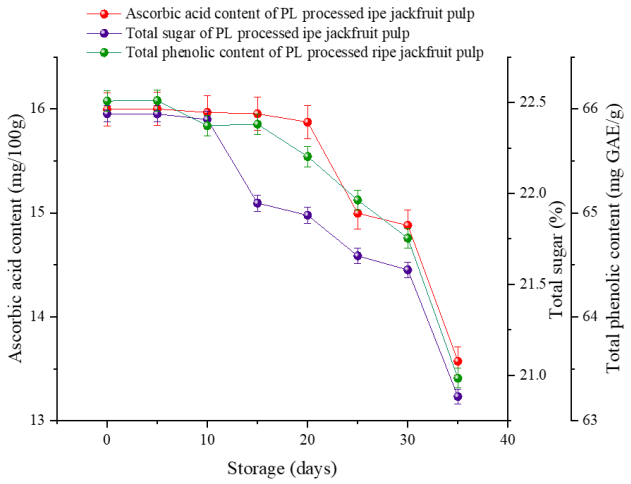


Fig 4.78 Effect of storage on AA, TPC and total sugar content of PL processed RJP

4.7.6 Effect of storage on Microbial activity of PL processed RJP

The initial microbial analysis of the control sample revealed a substantial load of microorganisms, with TAM present at 3.8 ± 1.20 log CFU/g and yeast and mold counts at 4 ± 1.30 log CFU/g. As the storage period progressed, the microbial counts exhibited a significant increase, reaching 6.2 ± 1.11log CFU/g for TAM (Table 4.18) and 6.5 ± 1.28 log CFU/g for yeast and mold by day 10. This rapid growth of microorganisms in the control sample suggests a lack of effective preservation methods, leading to a potential decrease in product quality and safety.

Similarly, the PL processed RJP demonstrated a remarkable reduction in initial microbial counts, with both TAM and yeast and mold counts being less than 1 log CFU/g at day 0. This significant decrease in microbial load was maintained up to 10 days of storage, indicating the effectiveness of PL processing in reducing the initial microbial burden in processed pulp. The low microbial counts observed in the PL processed RJP during the initial storage period suggest that this method can be a valuable tool in extending the shelf life of jackfruit bulbs.

However, from day 15 onward, a gradual increase in microbial counts was observed in the PL processed jackfruit pulp. By day 35, the TAM had reached 6.27 ± 1.33 log CFU/g, and yeast and mold counts were at 6.48 ± 2.14 log CFU/g, indicating a loss of effectiveness of the PL processing method over extended storage periods. This increase in microbial counts may be attributed to the potential re-contamination of the samples or the development of resistance to the PL treatment. Nevertheless, the PL processing method still demonstrated a significant delay in microbial growth compared to the control sample, highlighting its potential as a valuable preservation technique for jackfruit pulp. The study's results align with the results of Bask *et al*. (2022), who found that the TAM count and yeast and mold count remained low, below 1 log CFU/mL in mixed fruit beverage, for 45 days. In contrast, the PL-treated beverages showed a different pattern, with microbial counts starting to rise from day 40 and reaching 6.78 ± 0.26 TAM count by day 46. According to Ferrario *et al.* (2014), the microbial inactivation achieved by PL treatment is a result of the synergistic effects of photochemical, photothermal, and photophysical mechanisms.

The shelf-life of the PL processed jackfruit pulp was estimated based on the microbial count in the beverage. A threshold of 6 log CFU mL^{-1} was considered an indicator of microbial spoilage, and the microbial count was deemed unacceptable to consumption (Permanand, and Vos, 2010; Unluturk and Atilgan, 2015). In our study, the microbial counts exceeded this threshold by day 35, indicating that the shelf-life of the PL processed jackfruit pulp was approximately 30 days. This approach is consistent with previous studies, such as Unluturk and Atilgan (2015), who used a similar method to estimate the shelf-life of UV-C treated white grape juice.

Table 4.18 Effect of storage on Microbial activity of PL processed RJP

Sample	Storage period (days)	Total aerobic mesophiles (log CFU/g)	Yeast and mould count (log CFU/g)
Control sample	0	3.80 ± 1.20	4.00 ± 1.30
	5	4.60 ± 0.12	5.20 ± 0.41
	10	6.20 ± 0.45	6.50 ± 1.14
PL processed RJP	0	<1	<1
	5	<1	<1
	10	<1	<1
	15	1.77 ± 0.45	1.87 ± 0.95
	20	2.10 ± 1.04	2.42 ± 0.47
	25	2.43 ± 1.14	2.89 ± 1.04
	30	2.67 ± 1.04	2.98 ± 0.47
	35	6.27 ± 0.33	6.48 ± 1.14

values are expressed in mean ±SD

4.7.7 Effect of storage on sensory analysis of PL processed RJP

The sensory analysis of PL processed RJP was conducted over a storage period of 40 days, assessing attributes such as colour, aroma, consistency/texture, and overall acceptability. RJP colour scores showed a slight decline from 6.4 ± 0.25 after processing to 5.9 ± 1.11 by day 40, indicating pigment degradation and potential browning reactions that affect the visual quality of the pulp. This decrease could be linked to the PL treatment itself, potentially promoting oxidation and pigment degradation (Lee *et al*., 2023). The aroma scores also fell from 6.8 ± 0.14 on day 0 to 6.10 ± 1.03 by day 40, suggesting a loss of freshness and aromatic compounds, likely due to the volatilization of these substances and possible microbial activities during storage (Zhao *et al.*, 2024). The PL treatment might have influenced the volatilization of aroma compounds, particularly sensitive volatile compounds that contribute to the fresh aroma of jackfruit pulp. The consistency/texture scores for PL showed a notable decline from 6.9 ± 0.89 on day 1 to 6.00 ± 1.03 by day 40, linked to the breakdown of cell walls and pectin substances, resulting in a softer and less desirable texture (Wang *et al.*, 2019). The PL treatment might have affected the cell wall structure, leading to changes in texture over time. Overall acceptability for PL decreased from 6.8 ± 0.15 on day 1 to 5.81 ± 0.66 by day 40, indicating a significant decline in sensory appeal over the storage

period due to combined changes in colour, aroma, and texture. This suggests that PL processing, while potentially effective in extending shelf life, might negatively impact the sensory attributes of jackfruit pulp over time. The declining sensory scores for RJP highlight the challenges in maintaining the sensory quality of PL processed jackfruit products over time. The decline in colour can be attributed to oxidative reactions and enzymatic browning, while aroma loss is likely due to the volatilization of aroma compounds and potential microbial activities. Changes in consistency/texture are often a result of enzymatic breakdown of cell wall components and moisture migration, exacerbated by PL treatment. Overall, while PL processing can extend the shelf life of jackfruit products by inactivating microorganisms and enzymes, the sensory quality deteriorates over time. This underscores the need for optimized storage conditions and the potential use of preservatives to maintain the sensory attributes and consumer acceptability of PL processed jackfruit products over extended periods.

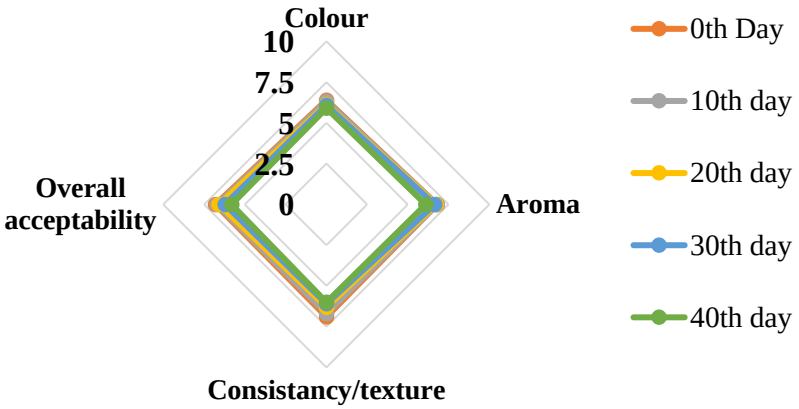


Fig. 4.79 Effect of storage on Sensory analysis of PL processed RJP