www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(6): 133-142

www.thepharmajournal.com
Received: 20-03-2023
Accepted: 23-04-2023

Prasad Naware
M. Tech. Scholar (APE), Dr. ASCAET, MPKV, Rahuri. Maharashtra, India

GB Yenge
Junior Research Officer Assistant Professor, Regional Sugarcane & Jaggery Research Station, Kolhapur, Maharashtra, India

GC Wakchaure
Senior Scientist, Agricultural Structure and Process Engineering, ICAR-NIASM, Baramati, Maharashtra, India

VP Kad
Associate Professor, Department of Agricultural Process Engineering, Dr. A.S.C.A.E.&T., MPKV, Rahuri, Maharashtra, India

Jagdish Rane
Principle Scientist, School of Water Stress Management, ICAR-NIASM, Baramati, Maharashtra, India

MS Jadhav
Ex. Professor & Head, Department of Agricultural Process Engineering, Dr. A.S.C.A.E.&T., MPKV, Rahuri, Maharashtra, India

Ware Keshav
M. Tech. Scholar (APE), Dr. ASCAET, MPKV, Rahuri. Maharashtra, India

Corresponding Author:
Prasad Naware
M. Tech. Scholar (APE), Dr. ASCAET, MPKV, Rahuri. Maharashtra, India

Thermal imaging and physico-chemical properties based maturity indices for custard apple (*Annona squamosa* L.) fruits

Prasad Naware, GB Yenge, GC Wakchaure, VP Kad, Jagdish Rane, MS Jadhav and Ware Keshav

Abstract

The present research entitled "Thermal imaging and physico-chemical properties based maturity indices for custard apple fruit (*Annona squamosa* L.)'' was studied at the ICAR-National Institute of Abiotic Stress Management, Baramati, Dist. Pune during 2021-2022. The objectives of present research were to determine changes in physico-chemical properties of custard apple fruit during maturation and to investigate the utility of thermal imaging for predicting the right harvesting time of custard apple fruit.

Custard apple (*Annona squamosa* L.) is climacteric, deciduous and subtropical fruit cropcommercially cultivated because of its hardy nature for abiotic and biotic stresses. After genotype, maturity stage at harvest is second most important influencing factor of fruit quality which depends on physicochemical properties at harvest. Objective type maturity indices determined by precise instruments are reliable and commercially applicable for fruits like custard apple where determination of right maturity level is critical. For this purpose the research was carried out to study the changes in physico-chemical and thermal characteristics of custard apple fruit during ripening. Considering the fact of heat release due to respiration the experiment of studying the temperature changes in custard apple fruit during ripening was carried out. Firstly harvesting of custard apple fruits according to aeroles opening levels namely A_0, A_{10}, A_{25}, A_{50}, A_{75}, A_{100} meaning 0%, 10%, 25%, 50%, 75%, 100% of aeroles opening during maturation. Harvested fruits of each stage were sampled after every 3 days of storage to determine changes in fruit surface temperature and physicochemical properties. Correlations between different properties of custard apple fruit is expressed using Pearson's correlation matrix. Based on the correlation between physico-chemical and thermal properties collective, reliable, nondestructive maturity indices for custard apple fruit is provided.

The quality attributes of custard apple fruits (Cv. Balanagar) at harvest of A_0, A_{10}, A_{25}, A_{50}, A_{75} andA_{100} includes true density (g/cc) of 0.96±0.01, 0.97±0.01, 0.99±0.01, 1.04±0.01, 1.08±0.01, 1.10±0.01; penetration force (g) of 2204.6±52.1, 2165.7±55.4, 2062.6±49.0, 1819.3±63.2,1517.8±49.9, 1352.6±54.0; cutting force (g) of 19882.9±671.8, 18574.5±453.0, 17163.9±883.9, 14591.8±342.9, 11615.9±401.5, 9633.5±445.1; pulp/seed ratio of3.2±0.2, 3.8±0.3, 5.3±0.4, 7.0±0.4, 7.7±0.3, 8.1±0.2;total soluble solids (°B) of 10.5±0.9, 11.0±0.9, 11.9±0.3, 12.9±0.3, 14.4±0.5, 16.2±0.9; total sugar (%)of 6.8±0.9, 7.8±0.4, 8.8±0.6, 11.0±0.5, 12.9±0.6, 15.2±0.6; titratable acidity (%) of 0.31±0.01, 0.30±0.01, 0.29±0.01, 0.26±0.01, 0.23±0.01, 0.21±0.01; moisture content (%) of 64.2±0.4, 64.8±0.4, 66.2±0.6, 68.4±0.6, 71.4±0.6, 72.6±0.5; fruit surface temp. (°C) of 27.8±0.1, 28.0±0.2, 28.1±0.2, 28.7±0.3, 29.1±0.1, 29.4±0.2 respectively.

The custard apple fruits of all stages were stored under laboratory condition (22-28°C). The different maturity stages at harvest significantly influence the physico-chemicals as well as thermal parameters of fruits. The fruits were analysed at the interval of three days by measuring the physiological weight loss, true density, penetration & cutting force, pulp/seed ratio, total soluble solids, titratable acidity, moisture content and fruit surface temperature. It is found that the physiological weight loss continuously increases throughout the entire storage period.True density increases cumulatively thereafter declines across all aeroles opening levels during storage. The cutting and penetration forces are continuously decreases throughout the storage period. Also the pulp/seed ratio increases and then declines. Total soluble solids, total sugar and moisture content increased in the early stage of storage and then decreased. The titratable acidity declines continuously throughout entire storage period. Fruit surface temperature increases and reaches its peak during ripening followed by decline at end of storage.

The experiments showed that fruits of A_0, A_{10}, A_{25} are of poor quality with lower fruit surface temperature while fruits of A_{50}, A_{75}, A_{100} having better fruit quality attributes with higher fruit surface temperature. The custard apple fruits with aeroles opening level A_{50} was found to be the best based on physico-chemical, thermal and correlation data.

Keywords: physicochemical properties, aeroles opening

1. Introduction

Custard apple (*Annona squamosa* L.) is climacteric, deciduous and subtropical fruit crop.

Because of its hardy nature for abiotic and biotic stresses custard apple is commercially cultivated on degraded lands having marginal soils by subsistence farmers (Ghawade *et al*., 2018) [19]. Though India's custard apple cultivation area is over 50000 ha with production of 395 thousand metric tons in year 2019-20, India's export is low (Department of Agriculture and Cooperation, 2020). Custard apple fruit is rich source of proteins, carbohydrates, minerals, vitamin A and vitamin C. Custard apple is a delicious and commercially important fruit having pleasant flavor, mild aroma, sweet taste, good nutritional and pharmaceutical properties like anti-diabetic, antioxidant, anti-dyslipidemic and anti-infective (Chikhalikar, *et al*. 2000; Khodifad *et al*., 2016) [8, 72]. Though custard apple pulp has great demand in dessert and ice-cream industry, storage of the fresh fruits has limitations because of its short shelf life of 2-3 days and cold storage is not promising because of chilling injury and development of unattractive brown colour on the skin which decreases the market value of fruit. Very short harvesting period of 2 months (October to November) of custard apple fruit usually leads to surplus production, wastage and distress sale (Purohit, 1995) [73]. After genotype, maturity stage at harvest is second most important influencing factor of fruit quality. Fruit quality and its postharvest life of fruits depend on physicochemical properties at harvest (Jha *et al*., 2006) [29]. With rapid increasing area under custard apple cultivation and its short shelf life, there is a need to develop suitable harvest technologies and machineries for custard apple (Jalikop, 2006) [27]. Some basic data of physicochemical properties are necessary for development of maturity indices. Physicochemical properties of custard apple fruits are affected by maturity stage at harvest and postharvest processing. The factors that affect Maturity indices are indicators for ensuring appropriate harvesting time of custard apple fruits to provide good market flexibility and fulfilment of satisfactory consumption quality to the consumer (Verma, 2000) [74]. Custard apple fruits are harvested when light green colour fruit shows initiation of cracking of the skin between the carpels with yellowish white colour. But short shelf life is reported at this maturity level (Bakane *et al.*, 2016) [4]. Due to inadequate knowledge farmers follow typical technique of estimating the maturity level of fruits based on visual examination of their surface color through our naked eyes can't serve the purpose. Custard apple fruit does not show major change fruit colour while ripening so we standardized the maturity levels by considering aeroles opening percentage. Moura *et al.* (2019) [15] determined the harvest time of sugar apples (*Annona squamosa* L.) in function of carpel interspace. He reported that fruits harvested in class3 (3.1 - 4.0mm) exhibited the better physical and physicochemical properties, with 8 days of postharvest life. Though traditional methods are inaccurate, destructive as well as time-consuming, use of established methods for maturity determination has no alternative and leads to postharvest losses up to 15% (ICAR-CIPHET, 2015). Combination of physico-chemical parameters can help in predicting the harvest maturity (Kader, 2002) [1]. Objective type maturity indices determined by precise instruments are reliable and commercially applicable. Especially in fruits like custard apple where determination of right maturity level is critical and influence postharvest quality. That's where first objective of this research work to determine changes in physico-chemical properties of custard apple fruit during maturation found relevant.

As climacteric fruit custard apple shows a spike in respiration and ethylene after harvesting, resulting in physico-chemical changes during ripening. Custard apple must be harvested under appropriate physiological conditions of maturity to get edible taste characteristics (Gamble J *et al*, 2010) [18]. Respiration within the fruits during maturation tends to release heat which influence the commodity's temperature. In fact the respiration rate is itself a function of the commodity's temperature (Intaravanne Y *et al*., 2012) [26]. Temperature parameters varies as per fruit due to unique, complex physicochemical properties of fruit. The temperature changes between mature and unripen fruits during their ripening process can be studied using thermal imaging. In past few years thermal imaging technology has grown fast and played vital role in various fields of agriculture including maturity estimation, bruise detection in fruits and vegetables. Thermal imaging is a non-invasive, non-contact and non-destructive technology used to determine the thermal properties and features of various objects. Thermal images are able to detect the level of fruit maturity through the heat released by the fruit during maturation (Danno *et al*. 1978) [10]. Sarun and Yuttana (2013) [58] used the IR technology to classify the whole fruits into immature, ripe and overripe stages for ripeness estimation meanwhile he observed that change in fruit surface temperature overtime is slower in ripen fruits because mature fruits have higher heat capacity than immature fruits. Soesiladi *et al.* (2021) [62] measured fruit thermal radiation to identify optimum harvestable maturity of avocado from 5 maturity levels and reported that the mature fruit had higher temperature than immature one. Thermal images are able to distinguish maturity level through temperature radiation emitted by the fruit or the radiation changes as the fruit ripens. Thermal imaging techniques have been applied on different fruits for evaluation of the quality and maturity of avocado, tomatoes, persimmon, japanese pears, apples, mango harumanis, ataulfo mangoes with an accuracy (Danno *et al*., 1978; Gurupatham *et al*., 2018; Hahn and Hernandez, 2005; Ishimwe *et al*., 2014;) [10, 20, 23, 75]. The previous studies on other fruits drives our motivation towards investigating the utility of thermal imaging for predicting right harvesting time of custard apple fruit. The research thus focus on experimental correlations of physicochemical and thermal properties of custard apple fruit.

Non-destructive methods are more effective than traditional methods as non-destructive methods are mainly based on physical, thermal properties which can correlate well with certain quality parameters of fruits (Khalifa, 2011) [37]. There exists some relation between physiological and biological activities of fruits as they are interconnected with each other. However insufficient attempts have been made to establish potential correlation between different properties of custard apple fruit. This research is undertaken to correlate physicochemical properties with fruit surface temperature during maturation for providing collective, reliable, nondestructive maturity indices of custard apple fruit which can be used as predictive tool. This research provides opportunities to the farmers by reducing overall losses as well as to researchers by developing portable maturity detection tools for further studies.

2. Materials and methodology

2.1 Source of raw materials

The experiment was carried out at the research farm of ICAR-

National Institute of Abiotic Stress Management (NIASM), Baramati, Pune, Maharashtra, India located at $18^0 9'37.51''$ N $74^0 29'52.23''$ E during September–December, 2021. The custard apple fruits were monitored from peanut size (<10mm) to harvesting. Batches of healthy and uniform sized custard apple fruits were harvested from custard apple orchard according to aeroles opening levels (AOL) and brought to laboratory for further investigation on thermal imaging and physico-chemical properties of custard apple fruit (Cv. Balanagar) during storage. As maturity detection of custard apple is critical, farmers harvest the fruits on visual inspection so we standardized 6 growth stages according to aeroles opening levels namely A_0, A_{10}, A_{25}, A_{50}, A_{75}, A_{100} meaning 0%, 10%, 25%, 50%, 75%, 100% of aeroles opening as shown in fig. 2.1. Estimating the maturity of custard apple fruit by comparing harvest and postharvest quality parameters of these AOLs is necessary for complete analysis of custard apple fruit.

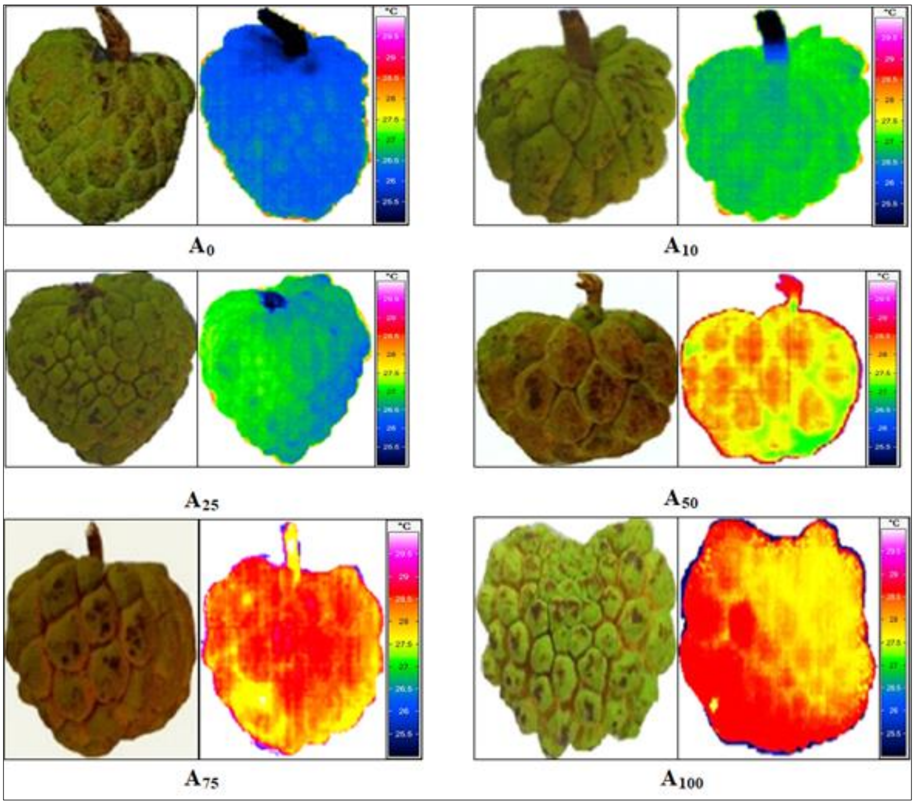

Fig 1: Thermal images of custard apple fruits of different aeroles opening levels

2.2 Physico-chemical analysis

Physiological characteristics at harvest influence fruit quality and postharvest life of fruit. Harvested fruits of each stage were sampled after every 3 days of storage to determine changes in fruit surface temperature and physicochemical properties. Measurements were taken under laboratory conditions up to 9 days of storage with three replications. Weight of fruit majorly affect the market value. Fruits weighed on electronic weighing balance accurately up to 0.01g for calculating the physiological loss in weight (PWL) after harvesting. Volume of fruit was determined by water displacement method thereby calculating true density (TD) suggested by Dhatt and Mahajan, 2007 [13]. Firmness proved as important aspect during transportation and storage of fruit which is measured using a Texture Analyzer (Model: TA. HD Plus, Stable Micro Systems, UK). Penetration force (PF) evaluated using a cylindrical puncture probe of 2.5 mm while cutting force (CF) was evaluated using cutting probe at a test speed of 5 mm/s. PF of unpeeled custard apple fruits expressed in grams (g) (Johnston *et al*., 2002) [28]. Pulp content defines the internal quality of fruit that why pulp/seed ratio (PSR) is measured by dividing weight pulp with weight of seeds separated after disruption of fruit. Total soluble solids (TSS, ºBrix) measurement of custard apple fruit was carried out with a portable digital refractometer (ERMA, Japan) at 25º (Ranganna 2005). Total sugar (TS) was estimated using Lane and Eynon method as described by Ranganna (1986) [56]. Titration of homogenized pulp samples against sugar working standard solution using Fehling's A, Fehling's B, HCL and NaOH solutions was done. The titratable acidity (TA) of custard apple pulp was determined by titration with 0.1N Sodium Hydroxide (NaOH) using phenolphthalein indicator as per method advocated by A.O.A.C. and Ranganna (2005). Moisture content (MC) in pulp was determined by hot air oven method at temperature of 70°C for 24 h as described by Ranganna S. (1986) [56].

2.3 Thermal Imaging

After harvesting of fruits at each AOL fruits were taken for thermal imaging (TI) using thermal camera (Vario CAM hr inspect 575, Jenoptic, Germany) 768 × 576 resolution operates in the far infrared wavelength spectrum (8-14 µm) with accuracy of 0.01 ºC. Thermal camera located 60 cm above the observing area fixed on a tripod stand and close-up thermal images were also taken for determining the surface temperature nondestructively. The thermal imaging study was carried out when the fruit had been acclimatized in laboratory condition and remaining custard apple samples were stored for ripening at room temperature (25±3 ºC). Thermal images were recorded and analyzed using IRBIS® software (Jenoptic,

Germany). Same samples that have been analyzed using TI were further examined for physicochemical parameters. Examine the relation between physicochemical and thermal imaged based properties using the regression value (R^2) and analysis of variance (ANOVA) and continued with the Least Significant Difference (LSD) test at a significant level of 5%.
This experiment was carried out with 10 observation parameters including thermal image, physical quality analysis (weight loss, true density, penetration force, cutting force, pulp/seed ratio) and chemical quality analysis (total soluble solids, total sugar, titrable acidity, moisture content).

2.4 Statistical analysis
The data obtained in physico-chemical and thermal image based properties is analyzed using Completely Randomized Design (CRD) for the statistical significance according to the procedure given by Pansey and Sukhatme (1985) [53]. Analysis of variance (ANOVA) was used to determine the effect of AOL on the physicochemical characteristics of the fruits and means were compared. Pearson's correlation matrix is determined for estimating relation between temperature and physicochemical properties of fruit during entire storage period. The adequacy of the model was determined by evaluating the coefficient of determination (R^2). Periodic changes in temperature and physicochemical characteristics at harvest were analyzed in triplicates (n = 3) and data were expressed as mean with±standard errors. Statistical significance was determined at $p < 0.05$ and $p<0.01$.

3. Result and Discussion
3.1 Physical quality attributes of custard apple fruits
Transportation and market value of fruits mainly influence by physical quality attributes including physiological loss in weight (PLW), true density (TD), penetration force (PF), cutting force (CF), pulp/seed ratio (PSR) and fruit surface temperature (FST) etc. were analyzed. All physical attributes shows statistical significance at $p < 0.05$ during storage. PLW caused due to respiration, transpiration, metabolic activities, maturity stage as well as storage temperature (Hafez *et al.*, 2019; Ma *et al.*, 2014) [22, 42].

3.1.1 Physiological loss in weight
As resulted from Fig.3.1 PLW of custard apple fruit is increasing across the AOLs at harvest and differs significantly within storage at room temperature. PLW cumulatively increased from day 0 up to start of senescence in all AOLs while maximum weight loss of 14.3%, 21.2%, 22.4% observed in A_{100}, A_{75}, A_{25} on day 3, day 6, day 9 of storage respectively. Kamble and Chavan (2005) [35] earlier reported similar trend of PLW in custard apple during storage. PLW of A_0, A_{10} and A_{25} increases less prominently from day 6 due to stone formation in custard apple fruits. Loss of weight during storage is majorly a function of transpiration through peel through stomatal cells thereby stone formation occurs (E. A. Baldwin, 1994) [14]. 17.2% weight loss in A_{50} resistant to stone formation is less than A_{75} on day 6.

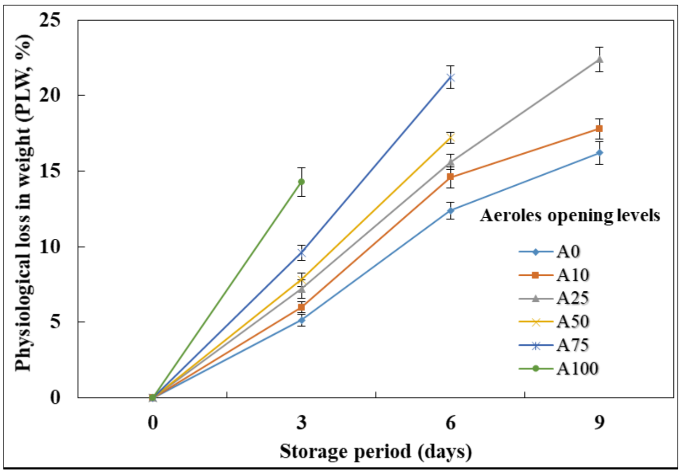

Fig 2: Changes in physiological weight loss of fruits during storage period

3.1.2 True density
True density (TD) collectively consider weight and volume of fruit which are extremely important factors during transportation. True density of fruits varies significantly and cumulative across AOLs during ripening thereafter declines as seen in fig. 3.2. Increase in TD of A_0, A_{10}, A_{25} from 0.96, 0.97, 0.99 g/cc to 1.01, 1.02, 1.03 g/cc on 6th day respectively followed by slight decrease after ripening. For the fruits and vegetables as density increases, thermal properties varies accordingly based on the moisture content (Sweat, 1974). TD of A_{50} and A_{75} at harvest is 1.04 and 1.08 g/cc differs significantly except during ripening. TD of A_{100} increases from 1.10 to 1.13 g/cc. The increase in TD during ripening is effect of volume shrinkage and conversion of starch into sugar with release of moisture. More mature fruits have higher TD than immature ones.

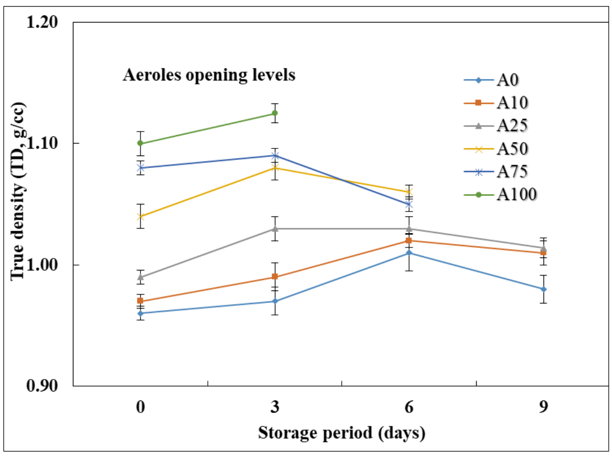

Fig 3: Changes in true density of fruits during storage period

3.1.3 Penetration force

Firmness provides resistance against physical damage during transport and postharvest handling of fruit. Reduction in firmness by softening of fruit is due to degradation as well as depolymerization of cell wall containing sugars and increase in moisture content (Bolivar, F. N. *et al*, 2009) [7]. The influence of AOL and storage period on penetration force (PF) of fruits were prominently significant ($p<0.05$). PF decreases insignificantly from A_0 to A_{25} while decreases more pronouncedly after A_{50} with minimum value of 1352.6 g observed at A_{100} (Vishnu Prasanna *et al*., 2000) [70]. PF of A_0, A_{10} and A_{25} differs significantly from 2204.6 g, 2165.7 g and 2062.6 g to 1408.2 g, 982 g and 712.2 g during storage except at day 0. PF decreases slowly in A_0, A_{10} and A_{25} due to stone formation but decreases drastically at A_{75} A_{100} during storage. PF of A_{50} decreases from 1819.3 g on day 0 to 503.5 g on 6th day of storage (Venkatram and Bhagwan, 2013) [3] as shown in fig. 3.3.

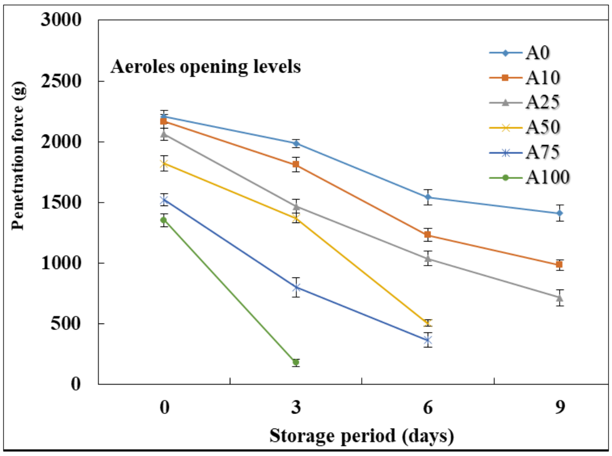

Fig 4: Changes in penetration strength of fruits during storage period

3.1.4 Cutting force

Force required to cut the entire fruit by using texture analyzer is cutting force (CF) which significantly influenced by maturity stages and storage period at ($p<0.05$) as shown in fig. 3.4. A_0, A_{10} and A_{25} does not varies significantly during storage except on day 3 with maximum CF observed in A_0 throughout storage resulted from stone formation. CF decreases significantly across A_{50}, A_{75} and A_{100} during storage with minimum value of 340.6 g was noticed after ripening on 3rd day (Tsau and Wu, 1990) [68]. Decrease in firmness including PF and CF concluded from ripening, moisture accumulation, degradation of pectic substances and transfer of water from peel to pulp (B. K. Dadzie *et al*., 1997) [6].

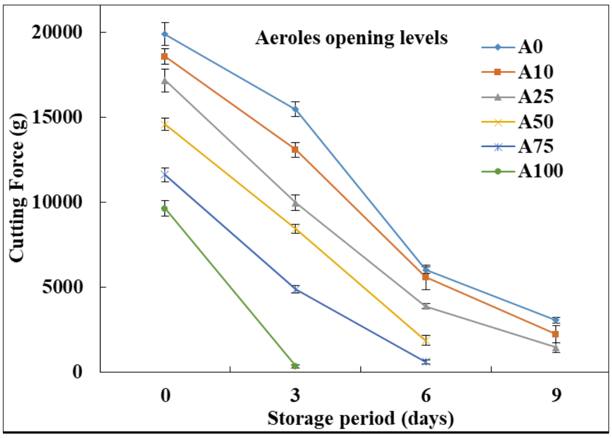

Fig 5: Changes in cutting strength of fruits during storage period

3.1.5 Pulp / seed ratio

Pulp content is an important factor which governs dessert quality of fruit during processing. Results from fig.3.5 confirms that pulp to seed ratio (PSR) differs significantly between AOLs with values of 3.2, 3.8, 5.3, 7.0, 7.7 and 8.1 at A_0, A_{10}, A_{25}, A_{50}, A_{75} and A_{100} respectively. PSR increases gradually during ripening and starts decreasing after that because of moisture transfer within pulp while seed weight mostly remains unchanged after maturity (Patil and Shanmugasundaram, 2015) [61]. PSR of A_0, A_{10} and A_{25} is less than A_{50}, A_{75} and A_{100} due to undergrown pulp content after harvesting. A_{50}, A_{75} and A_{100} varies insignificantly with maximum value recorded at A_{100} showing increase in PSR except A_{75} during storage.

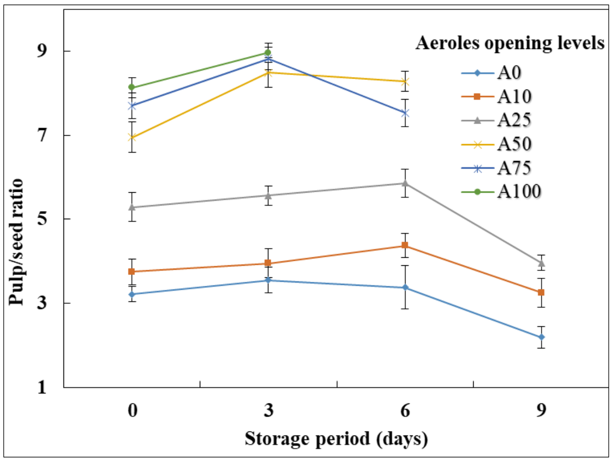

Fig 6: Changes in pulp/seed ratio of fruits during storage period

3.1.6 Fruit surface temperature

Fruit surface temperature (FST) is function of physicochemical properties of fruit during ripening. Ripening involves in heat release which was recorded by thermal imaging to predict the maturity level. It is proved from fig. 3.6 that temperature strongly influences the ripening of fruit. Increase in FST across all AOLs differs significantly on 3rd day. FST of A_0, A_{10} and A_{25} does not differ significantly increases up to 6th day then decreases. Maximum FST of

29.39 ºC at A_{100} decreases to 28.84 ºC during storage. FST of A_{50} and A_{75} increases up to 3rd day followed by decrease (WK Fauziah *et al.* 2021) [17].

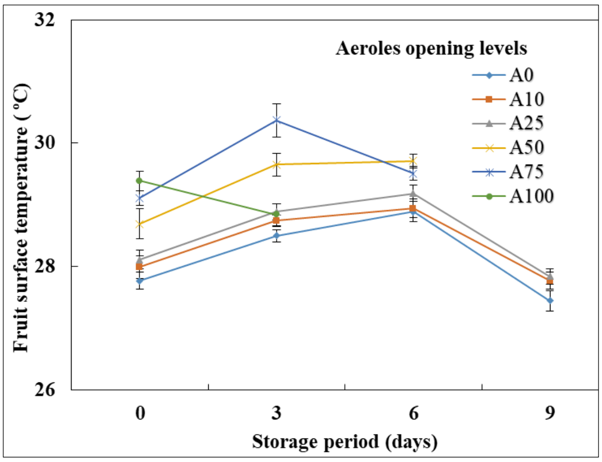

Fig 7: Changes in fruit surface temperature during storage period

3.2 Chemical quality attributes of custard apple fruits

3.2.1 Total soluble solids

Total soluble solids (TSS) is important quality attribute of fruits internal quality mainly 75-80% is sugar. TSS shows increasing trend upto ripening and starts decreasing after that (Bolivar F. N. *et al.*, 2009) [7]. Fig. 3.7 revealed that the storage period shows significant difference ($p<0.05$) for TSS across AOL. The highest TSS was observed in custard apple fruit harvested at A_{100} after 3 day of storage followed by custard apple fruit harvested at A_{75} after 3 day of storage. Freshly harvested custard apple fruits of all AOL does not differ significantly ($p<0.05$) also shows lowest value of TSS. Highest value of TSS (25.4ºB) recorded in A_{100} after 3 days however A_{50} shows TSS value of 22.5ºB highest after 6th day of storage (A. Venkatram *et al.*, 2013; Gutierrez *et al.*, 1994) [3, 21].

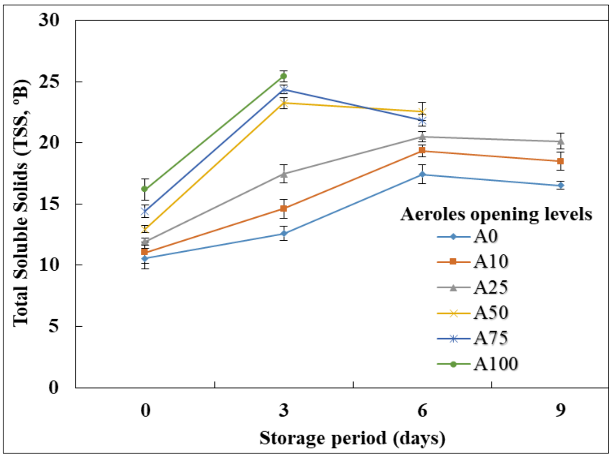

Fig 8: Changes in total soluble solids of fruits during storage period

3.2.2 Total sugars

A significant difference ($p<0.05$) existed in total sugar (TS) between AOL and storage duration. Fig. 3.8 shows steady increase in TS followed by slight decline in all AOL during 9 days of storage. Othman C. O. *et al.* (2014) [50] recorded similar observations in soursop fruits. Highest TS (23%) was recorded in A_{100} at 3rd day of storage while lowest TS (6.8%) was recorded in A_0 at harvest. This is proof that higher the TS lower the TA which indicate that highest metabolic activities happens in over ripen stage. Enzymatic breakdown of starch polymers into sugars leads to increase in TS and MC of fruits (Bolivar F. N. *et al.*, 2009; Beerh *et al.*, 1983) [7, 5].

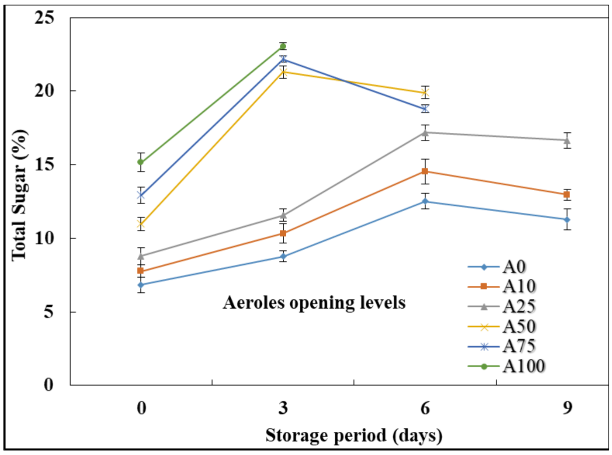

Fig 9: Changes in total sugars of fruits during storage period

3.2.3 Titrable acidity

From fig. 3.9 it can be seen that the AOL and storage period significantly influenced titrable acidity (TA) of custard apple fruit. Freshly harvested fruits of all AOL shows highest value of TA within storage period. Particularly highest TA (0.31) was recorded in A_0 at 0 day of storage whereas lowest TA (0.16) was recorded in A_{100} at 3rd day of storage. Vishnu Prasanna *et al.*, (2000) [70] found similar results earlier. Decrease in TA at ripening across all AOL was observed due to utilization of acids during respiration. TA starts increasing after senescence as observed in A_0, A_{10} and A_{25} after 6th day of storage (Sravanthi T. *et al.*, 2014) [63].

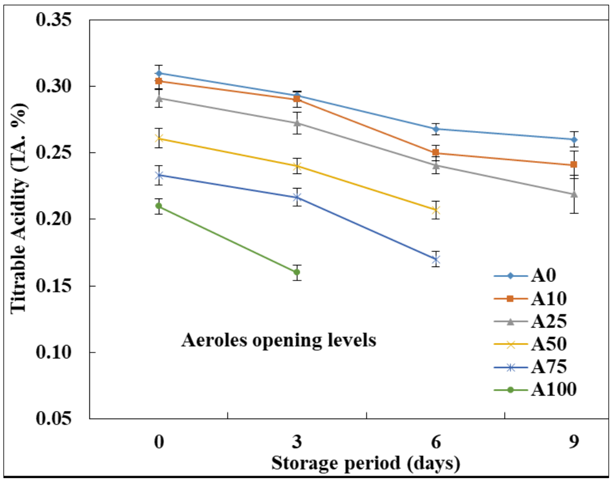

Fig 10: Changes in titrable acidity of fruits during storage period

3.2.4 Moisture content

As shown in fig. 3.10 moisture content (MC) of custard apple fruit significantly influenced ($p<0.05$) by AOL and storage period. The results revealed an significant increase in MC of fruits after 3 days of storage in A_{50}, A_{75} and A_{100}, while a steady increase in A_0, A_{10} and A_{25} upto 6 days of storage followed by decline in MC value. A_{100} shows highest MC (75.8%) at 3rd day but A_{50} shows MC value of 72.5% which is highest at 6th day of storage (Esther Hellen Lugwisha *et al.*, 2016) [16].

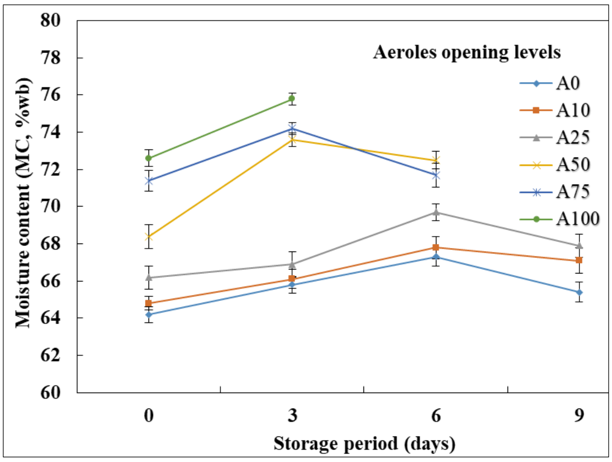

Fig 11: Changes in moisture content of fruits during storage period

3.3 Correlation between different quality attributes of custard apple fruit

In order to study more detailed insights of physicochemical changes during ripening Pearson's correlation matrix was performed which indicate interdependence of different quality attributes of fruit. The results from table 3.1 shows the Pearson's correlation coefficient for quality attributes of custard apple fruit. Mean values of physicochemical property changes throughout storage were significantly correlated at ($p<0.05$) and ($p<0.01$). Most of physicochemical properties are correlated except PLW, which shows nonsignificant correlation with other properties. There were significantly positive correlations between AOL and TD (r=0.99), PSR (r=0.94), FST (r=0.82), TSS (r=0.95), TS (r=0.96), MC (r=0.98) but negative correlations between AOL and PF (r=-0.98), CF (r=-0.96), TA (r=-1) respectively. Fruit quality attributes against TD revealed that AO, PSR, FST, TSS, TS, MC were positively correlated while PF, CF, TA, PLW were negatively correlated with TD. This means that TD increases as AO increases but PF and CF decreases during ripening. PF and CF positively correlated with TA only as both parameters shows declining trend with increasing AO. This means pulp becomes soft, acids converted into sugars as ripening proceeds with increasing AO. Similarly, Barragan-Iglesias *et al.* (2018) [76] recorded a decline on papaya firmness during the ripening process. Some strong positive correlations of AO, TD, FST, TSS, TS, MC with PSR at ($p<0.01$) and some negative correlation of PF, CF, TA with PSR at ($p<0.01$) were observed. Pulp constitute major portion of fruit because of that almost all quality attributes gets affected by PSR. FST represents the eternal characteristics of fruit as heat releases from physicochemical activities during ripening. Maximum PSR. Maximum pulp means high TSS, TS and MC leads to high chemical activities resulted in FST correlated positively. Apart from that TA, PF, CF correlated negatively with FST at ($p<0.05$) during ripening. These correlations of quality attributes with FST could give idea about internal quality of fruit nondestructively. Pearson's correlation matrix shows TS, MC, AO, TD, PSR and FST were positively correlated with TSS respectively as these values increases as per TSS. TA, PF, CF were correlated negatively with TSS as these values decreases as TSS increases within storage. TS follows similar trend of TSS because TS is a major constituent of TSS. TA positively correlated with PF, CF because both decreases with TA as acids gets consumed during ripening to form sugars. TA decreases with increase in AO, TD, PSR, FST, TSS, TS, MC so correlated negatively at ($p<0.01$). Increase in chemical activity leads to hydrolysis of pulp which ultimately increase MC of fruit. AO, TD, PSR, FST, TSS, TS were positively correlated with MC but PF, CF, TA were negatively correlated.

Table 1: Pearson's correlation matrix between quality attributes of custard apple fruit

Quality attributes	Aeroles Opening (AO, %)	Physiological loss in weight (PLW, % wb)	True density (TD, g/cc)	Penetration force (PF, g)	Cutting force (CF, g)	Pulp /seed Ratio (PSR)	Fruit surface temperature (FST, °C)	Total soluble solids (TSS,°B)	Total sugar (%)	Titrable acidity (TA, %)	Moisture content (MC, %wb)
AO (%)	1.00**										
PLW (%)	-0.37ns	1.00**									
TD (g/cc)	0.99**	-0.40 ns	1.00**								
PF (g)	-0.98**	0.17 ns	-0.96**	1.00**							
CF (g)	-0.96**	0.12 ns	-0.94**	0.99**	1.00**						
PSR	0.94**	-0.29 ns	0.97**	-0.93**	-0.90*	1.00**					
FST (°C)	0.82*	-0.10 ns	0.83*	-0.83*	-0.79ns	0.93**	1.00**				
TSS (°B)	0.95**	-0.20 ns	0.97**	-0.97**	-0.94**	0.99**	0.91*	1.00**			
TS (%)	0.96**	-0.28 ns	0.98**	-0.95**	-0.92**	1.00**	0.92*	0.99**	1.00**		
TA (%)	-1.00**	0.33 ns	-0.99**	0.98**	0.97**	-0.94**	-0.82*	-0.95**	-0.95*	1.00**	
MC(%wb)	0.98**	-0.39 ns	0.99**	-0.95**	-0.92**	0.98**	0.89*	0.97**	0.99**	-0.98**	1.00**

** indicates correlation is significant at 0.01 level, * indicates correlation is significant at the 0.05 level and ns indicates correlation is non-significant

4. Conclusion

The custard apple fruits (*Cv.* Balanagar) with aeroles opening level A_{50} indicates the best harvesting stage based on physico-chemical and thermal data as resulted in fig. 4.1. Blackening of fruit skin is observed in A_0, A_{10}, A_{25} due to moisture evaporation as well as early harvesting as shown in fig. 4.2. Correlation matrix and thermal imaging provides adequate utility for identifying the maturity stage of fruits.

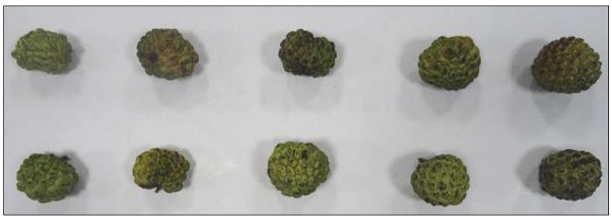

Fig 12: Marketable custard apple fruits of A_{50} at 6 days of storage

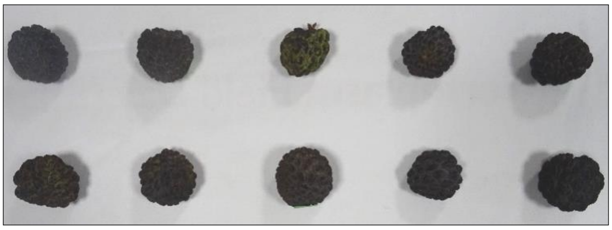

Fig 13: Blackening of skin in custard apple fruit

5. References

1. Kader Diane M Barrett. Classification, composition of fruits and post-harvest maintenance of quality. 2nd Edition: Science and Technology. CRC Press; c2002. p. 3-22.
2. OAC. Official methods of analysis. 15th edition Washington DC. Association of official analytical chemists; c1990.
3. Venkatram, Bhagwan A. Storage life improvement of custard apple (*Annona squamosa* L.) 'Balanagar' fruits by post-harvest application of antioxidants. Journal of Applied Horticulture, 2013, 15(3)
4. Bakane PH, Gajabe MH, Khakare MB, Dange MM, Khedkar MB, Manjeet P. Study on ripening of custard apple fruit (*Annona squamosa* L.). International Journal Agriculture Sciences. 2016;8:1844-1846.
5. Beerh OP, Giridhar N, Raghuramaiah B. Custard apple (*Annona squamosa* L.) Physico-morphological characters and chemical composition. Indian food packer; c1983.
6. Dadzie BK, Orchard JE. Routine Post-Harvest Screening of Banana/Plantain Hybrids: Criteria and Methods, International Plant Genetic Resources Institute, Rome, Italy; c1997.
7. Bolivar FN, Saucedo VC, Solis PS, Sauri DE. Ripening of sugar apple fruits (*Annona squamosa* L.) developed in Yucatan, Mexico. Agrociencia. 2009;43:133-141.
8. Chikhalikar NV, Sahoo AK, Singhal RS, Kulkarni PR. Studies on frozen pourable custard apple (*Annona squamosa* L.) pulp using cryoprotectants, Journal of the Science of Food and Agriculture. 2000;80:1339-1342.
9. Cherie D, Rini R, Makky M. Determination of the optimum harvest window and quality attributes of oil palm fresh fruit bunch using non-destructive shortwave infrared spectroscopy. AIP Conference Proceedings. 2019;2155(1):020034.
10. Danno A, Miyazato M, Ishiguro E. Quality Evaluation of Agricultural Products by Infrared Imaging Method. Memoirs of the Faculty of Agriculture, Kagoshima University. 1978;14:123-138.
11. Debora S Mendes, Marlon CT Pereira. Phenological characterization and temperature requirements of *Annona squamosa* L. in the Brazilian semiarid region. Anais da Academia Brasileira de Ciências. 2017;89(3):2293-2304
12. Development and ripening. Journal of Horticultural Science and Biotechnology, 70(4):569-572.
13. Dhatt AS, Mahajan BVC. Horticulture Post Harvest Technology: Harvesting, Handling and Storage of Horticultural Crops Punjab Horticultural Postharvest Technology Centre, Punjab Agricultural University Campus, Ludhiana; c2007. p. 2-3.
14. Baldwin EA, Hagenmaier R, Bai J, Krochta JM. Edible coatings and films to improve food quality 1, CRC Press London; 1994. p. 25.
15. Elias Moura, Chagas P, Chagas E, Oliveira R, Araújo W, Sobral S, *et al*. Phenological study of sugar apple (*Annona squamosa* L.) in dystrophic yellow latosol under the savanna conditions of Roraima. Australian Journal of Crop Science. 2019;13(09):1467-1472.
16. Esther Hellen Lugwisha, Christina Fabian, Othman Chande Othman. Postharvest changes in physicochemical properties and levels of some inorganic elements in sugar apple (*Annona squamosa* L.) fruits of coast region, Tanzania. Journal of Food and Nutrition Sciences. 2016;4(3):41-48.
17. WK Fauziah M Makky Santosa, Cherie D. Thermal vision of oil palm fruits under difference ripeness quality. IOP Conference Series: Earth and Environmental Science. 2021;644:012044.
18. Gamble J, Harker FR, Jaeger SR, White A, Bava C, Beresford M, *et al*. Postharvest Biol. Technol. 2010;57:35-43.
19. Ghawade PM, Supe VS, Pimpalpalle LV, Tayade SA. Morphological characterization of custard apple genotypes. Journal of Pharmacognosy and Phytochemistry. 2018;7(1):1029-1032.
20. Gurupatham SK, Ilksoy Erhan, Jacob Nick, Van DH, Kevin, Fahad F. Fruit Ripeness Estimation for Avocado Using Thermal Imaging. International Mechanical Engineering Congress and Exposition. 2018;8(B):9-15.
21. Gutierrez M, Lahoz JM, Sola MM, Pascual L, Vargas AM. Post-harvest changes in total soluble solids and tissue pH of chermoya fruits stored at chilling and non-chilling temperature. Journal of Horticultural Science. 1994;69:459-63.
22. Hafez OM, Saleh MA, Thabet AYI, Eldashsouri MF. Keeping 'Le Conte' pear fruits quality dur- ing storage life and marketing by using some natural medicinal plant extracts. Eurasia Journal of Bioscience. 2019;13(2):2203-2210.
23. Hahn F, Hernandez G. Comparison of maturity detection of Ataulfo mangoes using thermal imaging and NIR, EFITA/WCCA Joint Congress on IT in Agri; c2005. p. 229-235.
24. Hahn F, Hernandez G. Comparison of Maturity Detection of Ataulfo Mangoes using Thermal Imaging and NIR. In Cunha J. B. and Morais R. (Eds). EFITA/WCCA Joint Congress, Vila Real, Portugal: Universidade de Tras-os-Montes e Alto Douro; c2005. p. 229-235.
25. Hellebrand HJ, Linke M, Herold B. Bruises and Ripeness of Apples Studied by Thermal Imaging. Institute of Agricultural Engineering (ATB) Potsdam, Germany; c2000.
26. Intaravanne Y, Sumriddetchkajorn S, Nukeaw J. Cell phone-based two-dimensional spectral analysis for banana ripeness estimation, Sens. and Actua. B: Chemical. 2012;168:390-394.
27. Jalikop SH. Custard apple. In: Hand Book of Horticulture, K.L. Chadha (ed.). ICAR pub., New Delhi, India; c2006. p. 109-114.
28. Jason W Johnston, Errol W Hewett, Maarten LATM Hertog. Postharvest softening of apple (Malus domestica) fruit: A review, New Zealand Journal of Crop and Horticultural Science, 2002;30(3):145-160.
29. Jha SN, Kingsly ARP, Chopra S. Physical and mechanical properties of mango during growth and storage for determination of maturity. J Food Eng.

2006;72(1):73-76.
30. Kachhadiya S, Jethva KR. Physico-Chemical Properties of Custard Apple. International Journal of Biochemistry Research & Review. 2017;20(1):1-13.
31. Kad VP, Patil AP, Nalawade SM. Studies on Engineering Properties of Custard Apple (*Annona squamosa* L.). Journal of Agriculture Research and Technology. 2017;42(3):197-203.
32. Kad VP, Jadhav MS, Nimbalkar CA. Studies on physical, morphological and rheological properties of custard apple (*Annona squamosa* L.). International Journal of Applied and Pure Science and Agriculture. 2016;2(4):140-147.
33. Kader AA. Fruit maturity, ripening, and quality relationships. Acta Horticulturae. 1999;(85):203-208.
34. Kader AA. Definition and evaluation for fresh horticultural crops. Postharvest technology of horticultural crops; c2002. p. 279-285.
35. Kamble PB, Chavan JK. Effects of postharvest treatments and storage temperature on shelf life of custard apple fruits. Journal of Food Science Technology. 2005;42(3):253-255.
36. Kamleshwar Goutam, Sharma TR, Verma BK, Chanderia UK, Pandey SK. Genetic Variability in Custard Apple Landraces of Madhya Pradesh, India. International Journal of Current Microbiology and Applied Sciences. 2019;8(10):2201-2209.
37. Khalifa S, Komarizadeh MH, Tousi B. Usage of fruit response to both force and forced vibration applied to assess fruit firmness- a review. Australian Journal of Crop Science. 2011;5(5):516-522.
38. Khanbarad Sonali C, Bakane PH. Physical and Mechanical Properties of Custard Apple Fruit (*Annona squamosa* L.). International Journal of Current Microbiology and Applied Sciences. 2020;9(9):2338-2347.
39. Kolekar TN, Tagad VB. Studies on physico-chemical properties of custard apple fruit. Indian Streams Research Journal. 2012;2(8):1-4.
40. Lane JH, Eynon L. Determination of reducing sugars by means of Fehling's solution with methylene blue as internal indicator. J Soc. Chem. Ind. Trans. 1923;42:32-36.
41. Makky M. Multi-modal Bio-metrics Evaluation for Non-destructive Age States Determination of Tomato Plants (*Solanum lycopersicum*). International Journal on Advanced Science; c2016.
42. Ma L, Cao J, Xu L, Zhang X, Wang Z, Jiang W. Effects of 1- methylcyclopropene in combination with chitosan oligosaccharides on postharvest quality of aprium fruits. Scientia Horticulturae. 2014;179:301305.
43. McCabe WL, Smith JC, Harriott, P. Unit operations of chemical engineering. New York: McGraw-Hill; c1986.
44. Meghana JN, Nataraja KH, Naik N, Kantharaju V, Manjula Karadiguddi, Mahantesha BN. Performance of different custard apple local selections (*Annona squamosa* L.) for yield and physical parameters. Journal of Pharmacognosy and Phytochemistry. 2019;9(1):781-785.
45. Mendes DS, Pereira MCT, Nietsche S, Silva JF, Rocha JS, Mendes AH, *et al*. Phenological characterization and temperature requirements of *Annona squamosa* L. in the Brazilian semiarid region. An Acad Bras Ciênc. 2017;89:2293-2304.
46. Mendoza F. Characterization of surface appearance and color in some fruits and vegetables by image analysis, Santiago de Chile; c2005.
47. Mohsenin NN. Physical properties of plant and animal materials. Gorden and breach science publication, New York; c1986.
48. Nag JL, Ajay Tiwari, Dikshit SN. Physico-chemical analysis of quality attributes in custard apple (*Annona squamosa* L.) genotypes. International Journal of Chemical Studies. 2018;6(5):810-814.
49. Nath A, Deka BC, Singh A, Patel RK, Paul D, Misra LK, *et al*., Extension of shelf life of pear fruits using different packaging materials. Journal of Food Science Technology. 2011;49:556563.
50. Othman CO, Fabian C, Lugwisha E. Post-harvest physicochemical properties of soursop (*Annona muricata* L.) fruits of coast region, Tanzania. Journal of Food and Nutrition Sciences. 2014;2(5):220-226.
51. Pal DK, Kumar SP. Changes in the physico-chemical and biochemical compositions of custard apple (*Annona squamosa* L.) fruits during growth; c1995.
52. Pandey N, Barve D. Phytochemical and pharmacological review on *Annona squamosa* Linn. International Journal of Research in Pharmaceutical and Biomedical Sciences. 2011;2(4):1404-1412.
53. Pansey VG, Sukhatme PV. Statistical methods for agricultural workers. 4th enlarged edition. ICAR Publication, New Delhi; c1985.
54. Parihar Pushpa, Hemant Kumar Panigrahi, Sangeeta Chandrakar. Standardization of Recipes of Custard Apple Jam and Analysis of Physico-Chemical Characteristics, Sensory Quality and Storage Behaviour. International Journal of Current Microbiology and Applied Sciences. 2018;7(12):1536-1546.
55. Paschalidis K, Tsaniklidis G, Wang B.-Q, Delis C, Trantas E, Loulakakis K, *et al*. The Interplay among Polyamines and Nitrogen in Plant Stress Responses. Plants. 2019;8:315.
56. Ranganna S. Manual of Analysis of fruit and vegetable products. Tata Mc Graw - Hill. Publishing co. Ltd., New Delhi; c1986. p. 89-90.
57. Sa'ad FSA, Shakaff AY, Zakaria A, Abdallah AH, Ibrahim. Maturity assessment of harumanis mango using thermal camera sensor. American Institute of Physics (AIP). 2017, 1808.
58. Sarun Sumriddetchkajorn, Yuttana Intaravanne. Two-Dimensional Fruit Ripeness Estimation using Thermal Imaging. Proceedings of SPIE - The International Society for Optical Engineering; c2013.
59. Sharma A, Bhatnagar P. INM in custard apple cv. Arka Sahan, College of Horticulture and Forestry, Jhalawar MPUAT, Udaipur. M.Sc thesis; c2011. p. 110.
60. Shelar SD, Kad VP, Nimbalkar CA, Turbatmat PA, Unde PA. Physico-morphological properties of pomogranate (*Punica granatum* L.) fruits; c2017.
61. Patil SK, Shanmugasundaram S. Physicochemical changes during ripening of Monthan Banana. International Journal of Technology Enhancement and Emerging Engineering Research. 2015;3:18-21.
62. Soesiladi Esti Widodo, Sri Waluyo, Zulferiyenni, Maya Dwi Putri. Measurement of Fruit Thermal Radiation to Identify Optimal Harvestable Maturity of Avocado (*Persea americana* Mill.). International Conference on

Science, Infrastructure Technology and Regional Development; c2021.

63. Sravanthi T, Kavitha W, Jayasimha RD. Studies on preservation and processing of custard apple (*Annona squamosa* L.) pulp. International Journal of Plant, Animal and Environmental Sciences. 2014;4(3):676-682.
64. Sudheer KP, Nawab A, Indira V. Post-Harvest Technology of Horticultural Crops, New Pitam Pura New Delhi; c2007. p. 1-47.
65. Sumriddetchkajorn S, Intaravanne Y. Methods and apparatus for determining ripeness levels using thermal imaging cameras, Thailand Patent Applications, 2012, 1201005829.
66. Swapnil Singh Chandel, Dikshit SN, Sharma HG. Collection and evaluation of custard apple (*Annona squamosa* L.) genotypes in Chhattisgarh plains. Journal of Pharmacognosy and Phytochemistry. 2018;SP2:149-152.
67. Thakur Bhagyashri, Desale RJ, Ashwini Mujhekar. Studies on Physico-Chemical Properties of Custard Apple Kalakand. International journal of agriculture and food sciences; c2017. p. 0974-8431, 1074-1075.
68. Tsau LM, Wu MC. Studies on the physico-chemical properties of post-harvest sugar apple. Acta Horticulturae. 1990;269:241-7.
69. Veraverbeke EA, Verboven P, Lammertyn J, Cronje P, De Baerdemaeke J, Nicolaï BM. Thermographic surface quality evaluation of apple. J Food Engineering. 2006;77(1):162-168.
70. Vishnu Prasanna KN, Sudhakar Rao DV, Shantha krishnamurthy. Studies on growth, development and storage of post-harvest handling of custard apple (*Annona squamosa* L.) Journal of Horticultural Sciences and Biotechnology. 2000;75(5):546-550.
71. Yashwant Kumar, Ajay Kumar Chandra, Ashutosh Dubey, Gajera HP. Fruit Morphology and Quality Parameter Studies of Global Custard Apple (*Annona squamosa* L.) Germplasms. International Journal of Current Microbiology and Applied Sciences. 2018;7(10):1297-1311.
72. Khodifad BC, Kumar N, Vyas DK, Seth N, Prem M. Pre and post-harvest practices, processing and value addition of custard apple. International Journal of Food and Fermentation Technology. 2016;6(2):219-31.
73. Purohit A, Ghilchik MW, Duncan L, Wang DY, Singh A, Walker MM, Reed MJ. Aromatase activity and interleukin-6 production by normal and malignant breast tissues. The Journal of Clinical Endocrinology & Metabolism. 1995 Oct 1;80(10):3052-8.
74. Verma R, Chen S, Feldman R, Schieltz D, Yates J, Dohmen J, *et al*. Proteasomal proteomics: identification of nucleotide-sensitive proteasome-interacting proteins by mass spectrometric analysis of affinity-purified proteasomes. Molecular biology of the cell. 2000 Oct 1;11(10):3425-39.
75. Ishimwe R, Abutaleb K, Ahmed F. Applications of thermal imaging in agriculture-A review. Advances in remote Sensing. 2014 Sep 3;3(03):128.
76. Barragán-Iglesias J, Méndez-Lagunas LL, Rodríguez-Ramírez J. Ripeness indexes and physicochemical changes of papaya (*Carica papaya* L. cv. Maradol) during ripening on-tree. Scientia Horticulturae. 2018 Jun 16;236:272-8.