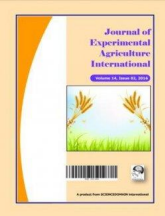

Journal of Experimental Agriculture International

27(4): 1-13, 2018; Article no.JEAI.44816
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Physical Characterization, Chemistry and Bioactive Compounds in Noni Fruit Harvested in Three Maturation Stages

Larissa de Sousa Sátiro[1*], Franciscleudo Bezerra da Costa[2], Jéssica Leite da Silva[3], Ana Marinho do Nascimento[3], Mahyara de Melo Santiago[2], Kalinne Passos dos Santos[2], Kátia Gomes da Silva[2], Sabrina Vieira de Sousa[2], Giuliana Naiara Barros Sales[4] and Tatiana Marinho Gadelha[5]

[1]Postgraduate Program in Agrarian Sciences, Biological Sciences and Health Center, Paraíba State University, Paraíba, Brazil.
[2]Agrofood Science and Technology Center, Campina Grande Federal University, Paraíba, Brazil.
[3]Postgraduate Program in Process Engineering, Science and Technology Center, Federal University of Campina Grande, Paraíba, Brazil.
[4]Postgraduate Program in Tropical Horticulture, Agro-Food Science and Technology Center, Campina Grande Federal University, Paraíba, Brazil.
[5]Teacher Training Center, Campina Grande Federal University, Paraíba, Brazil.

Authors' contributions

This work was carried out in collaboration between all authors. Author LSS elaborated the study, participated in all the steps of conducting and writing the manuscript. Author FBC consists of the research supervisor, showing the alternatives of conducting and evaluating the data, assisting in the statistical part of the work. Authors JLS and AMN did the decisive in the correction phase, showing alternatives to enrich the information work. Authors MMS and KPS participated in the process of planning and conducting the experiment. Authors KGS and SVS were of paramount importance in the conduction and evaluation of the experiment. Authors GNBS and TMG participated during the physical and chemical evaluations in the laboratory after harvesting. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2018/44816
Editor(s):
(1) Dr. Zijian Li, Department of Civil Engineering, Case Western Reserve University, USA.
Reviewers:
(1) Esraa Ashraf Ahmed ElHawary, Ain Shams University, Egypt.
(2) V. Vasanthabharathi, Annamalai University, India.
(3) Omaima Mohamed Hafez, National Research Centre, Egypt.
Complete Peer review History: http://www.sciencedomain.org/review-history/26934

Original Research Article

Received 09 August 2018
Accepted 22 October 2018
Published 31 October 2018

**Corresponding author: E-mail: lariisatiro@gmail.com;*

ABSTRACT

Objective: The objective was to determine the physical, physicochemical and bioactive compounds of noni fruits harvested at three maturation stages.
Experimental Design: The experiment was conducted in a completely randomized design, where the treatments were composed of three stages of maturation (green, pre-mature and mature), with five replicates containing two fruits each, totalling 10 fruits for each maturation stage.
Place of Study: the experiment was carried out at the Laboratory of Chemistry, Biochemistry and Food Analysis of the Center for Food Science and Technology - CCTA, Federal University of Campina Grande - UFCG, Pombal campus, Paraíba.
Methodology: After sorting, the fruits were sanitised in running water to remove surface dirt and perform the physical, physicochemical and bioactive compounds analyses.
Results: it was observed the irregular growth and oval shape of the fruits. Based on the physical-chemical analysis and bioactive compounds, it is verified that the maturation stage interferes with the quality of noni fruits.
Conclusion: The high levels of ascorbic acid and phenolic compounds, especially in mature fruit, indicate the potential use of this fruit for the production of functional foods.

Keywords: Morinda citrifolia L.; ascorbic acid; phenolic compounds.

1. INTRODUCTION

Morinda citrifolia L., popularly known as Noni is a fruit tree belonging to the Rubiaceae family widely distributed in tropical regions [1]. The noni fruits are very distinct which facilitates their recognition, the white tubular flowers form clusters on the young fruit, the fruit of the syncarpous type can grow about 5-10 cm in length and transform from a greenish to a white colour translucent yellow when fully ripe [2].

All the noni components are used for consumption, however, the most used part is its fruits, followed by the roots and leaves, and its consumption is mainly related to its antioxidant capacity [3]. In Brazil, its use is attributed to several beneficial effects, which according to the empirical knowledge are, antibacterial, antiviral, antifungal, antitumor, antihelmintic, analgesic, anti-inflammatory, hypotensive and immune stimulating activity [4].

About 200 phytochemical compounds have already been identified in this plant, however, its phytochemical composition has not yet been fully elucidated [5]. It is known that the chemical compositions and their concentrations are related not only to the part of the plant but also to the place where it was cultivated and the harvest time [6]. The fruit is considered a powerful natural antioxidant, in which its daily consumption aids in the immune system, increasing the capacity of absorption of the nutrients in the cells. A component found in the fruit is the proxeronine precursor of the alkaloid Xeronina, which is responsible for the activation of catalytic enzymes of cellular metabolism [7].

The demand of the consumer market and the search for in natural products has aroused the interest of research on exotic fruits, such as noni, the findings have the purpose of providing the population with nutrient-rich food and consequently a healthier life [8]. One of the requirements of the fresh fruit market is the quality assurance of the products. The modern concept of quality involves factors such as physical and chemical characteristics of the product, appearance, taste, sanity, nutrition, as well as the processes used in its production and commercialisation [9].

Given the above, this study aimed to evaluate the post-harvest quality of noni fruits harvested at three maturation stages, evaluating physical, physicochemical and bioactive compounds, in order to evaluate the influence of the maturation stage on the quality of the fruit.

2. MATERIALS AND METHODS

Noni fruits from plants located at the Agro-Food Science and Technology Center, Federal University of Campina Grande, Pombal Campus, Paraíba, Brazil, were used. Characterised by the geographical coordinates of 6°48'16 " of latitude S and 37°49'15 "of longitude W, at an altitude of 175 m. According to the classification of Köppen, the predominant climate in the region is BSh, that is, semi-arid hot, with annual precipitation of 750 mm [10].

2.1 Obtaining Plant Material and Experimental Procedure

The fruits were harvested manually, from 07:00 to 08:00 a.m, packed in polyethylene bags and taken to the Laboratory of Chemistry, Biochemistry and Food Analysis of the CCTA. After harvest, the fruits were visually selected for absence of injury in order to obtain uniform and quality samples. After the selection, the fruits were classified in three stages of maturation according to the colour of the bark, being green to all-green peel (Fig. 1A), pre-ripe to green peel with yellow spots (Fig. 1B) and ripe to peel yellowish white (Fig. 1C).

The experimental design was completely randomised, where the treatments were composed of three maturation stages (green, pre-mature and mature), with five replicates containing two fruits each, totalling 10 fruits for each maturation stage.

2.2 Physical Analysis

After sorting, the fruits were sanitised in running water in order to remove the superficial dirt and perform the physical analyses in the following characteristics:

- Fresh mass (g): the fruits were weighed in a semi-analytic digital scale (Balmak model) with an accuracy of 0.01 g.
- Firmness (N): was determined with the aid of a digital texturometer bench (Model Instrutherm) manual operation with ferrule 8 mm in diameter, with two readings on each fruit.
- Longitudinal and transverse length (mm): were estimated with the aid of a digital caliper (Digimess model).
- Colorimetry: the fruits were split in half to obtain the values of the peel and the pulp, and the readings were made in duplicate on two opposite sides of the fruits. The analysis was determined in the CIELAB system using a colorimeter (model CR 300 Tokyo) in three parameters being: luminosity (L*), coordinate a* and coordinate b* [11].

2.3 Physicochemical Analysis

In order to perform the physicochemical analyzes, it was necessary to obtain the fruit extract, the fruit was split in half and processed in a fruit centrifuge (Liquafruits Power model). The extract was evaluated for the following characteristics:

- Hydrogen ionic potential: pH was determined with direct reading in the extract in digital potentiometer bench (model DM-22).
- Concentration of H + ions (μM): estimated from the conversion of the obtained pH values by the equation $[H^+] = 10^{-pH}$.
- Titratable acidity (% citric acid): the acidity was measured in 5 g of extract, homogenised in 45 mL of distilled water. The solution containing the sample was titrated with 0.1 N NaOH until reaching the turning point of the phenolphthalein indicator, being expressed in percentage of citric acid according to the recommendations of the Adolfo Lutz Institute [12].
- Soluble solids (%): was determined by a direct reading of the extract in a digital refractometer (model AR-200, Reichert) with automatic temperature compensation. The analysis was performed in duplicate for each repetition and, where necessary, the refractometer was calibrated with distilled water.
- Solid soluble/titratable acidity ratio (SS / AT): was obtained by dividing the soluble solids values by the values of the titratable acidity.

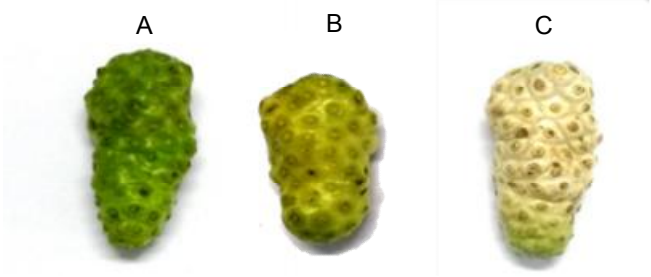

Fig. 1. Fruits of *Morinda citrifolia* L. at the green stages of maturation (A), pre-mature (B) and mature (C)

- Total soluble sugars (g / 100 g) were determined by the method of Yemm and Willis [13], from the dilution of 0.5 g of sample in 100 mL of distilled water. Sample preparation was performed in an ice bath, adding a 200 µL aliquot plus 800 µL of distilled water and 2000 µL of anthrone followed by stirring and standing in a water bath at 100°C for 3 minutes. The sample readings were performed in a spectrophotometer at the absorbance of 620 nm, using as reference the glucose to obtain the standard curve.

2.4 Analyzes of Bioactive Compounds

The bioactive compounds were evaluated according to the quantification of total chlorophyll, total carotenoids, ascorbic acid, total phenolic compounds, flavonoids, and anthocyanins, as described below:

- Chlorophyll and carotenoids (mg / 100 g) were determined as described by Lichtenthaler [14] with adaptations, where an aliquot of 500 µL of noni extract was homogenised in a mortar with 0.2 g of calcium carbonate and 5 mL of acetone 80%, in dark environment. The extract was poured into falcon tubes wrapped in foil and centrifuged in a cooled micro-processed digital centrifuge (model CT-5000R) for 10 minutes at 3000 rpm. After centrifugation, the samples were read in a spectrophotometer (model SP-110 Meter), at the absorbances of 470, 646 and 663 nm.
- Ascorbic acid (mg / 100 g): the ascorbic acid content was estimated by titration, according to the methodology described by the Adolfo Lutz Institute [12]. To quantify the content was weighed 1 g sample and this was homogenised with 50 ml of 1% oxalic acid. Then the solutions were titrated with the Tillmans solution (2,6 dichloro-phenol-indophenol 0.02%) until the permanent clear pink colour was reached.
- Phenolic compounds (mg / 100 g) were estimated by the method described by Waterhouse [15], from the dilution of 0.5 g of noni extract to 50 ml of distilled water. From the dilution an aliquot of 500 µL was withdrawn, with the addition of 100 µL of the Folin-Ciocalteu reagent, followed by stirring and standing for 5 minutes. After the reaction time, 30 µL of 20% sodium carbonate was added, followed by further stirring and resting in a water bath (Fisatom model) for 30 minutes. The standard curve was prepared with gallic acid and the readings were performed in a spectrophotometer (model SP-110 Meter) at an absorbance of 765 nm.
- Flavonoids and anthocyanins (mg / 100 g) were determined by the method described by Francis [16], where 1 g of sample plus 10 mL of the ethanol: HCL mixture was weighed, which was macerated in a mortar and poured into a tube falcon wrapped with foil, the tubes remained refrigerated for 24 hours. After resting, the samples were filtered using filter paper and the spectrophotometer readings (model SP-110 Meter), at 374 nm absorbance for flavonoids and at 535 nm for anthocyanins.

2.5 Statistical Analysis

The data obtained were submitted to analysis of variance when a significant effect was detected for the F test, the Tukey test was applied at a 5% probability level. To evaluate the influence of one parameter on the other, the coefficients da Pearson correlation. Data were analyzed with the aid of the AgroEstat® statistical package [17].

3. RESULTS AND DISCUSSION

3.1 Physical Characterisation

It was observed a significant decrease in the fresh mass of the noni fruits in the maturation stages (Fig. 2A), the fruit of the green stage being the highest value with 114.8 g, followed by the pre-mature stage with 100.0 g and mature with 85.8 g. It was verified that the maturation progression promoted smaller fruits, however, this fact may be related to the irregular growth of the fruits, which allows finding in the same plant, fruits of the same maturation stage with different sizes, as well as, fruit with stages of maturation stages with greater weight than fruits with advanced maturation stages. In the work of Nery et al. [18], different results were found in this work, where the mature fruits had a fresh mass of 158.18 g. In the study by Silva et al. [19] it was observed an increase of these values being 47.16 g in the green stage and 56.33 g in the pre-mature, nevertheless, the fruits of the mature stage were of 50.08 g, it is noticed that there was a reduction of the values when compared with the pre-mature, it was verified that the divergent results reported in the literature corroborate the irregular growth of noni fruits.

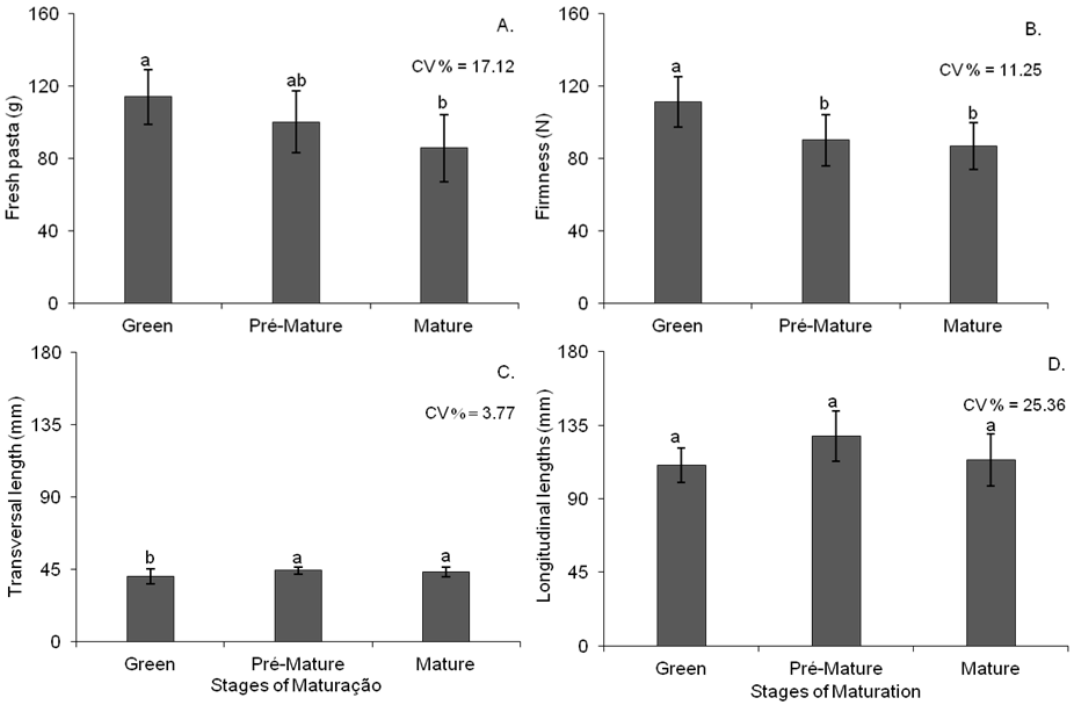

Fig. 2. Fresh pasta (A), firmness (B), the transverse length (C) and longitudinal (D) of noni fruits harvested at three maturation stages

The vertical bar represents the standard deviation of the means. (CV = coefficient of variation)

The firmness of the fruit differs significantly between the stages of maturation (Fig. 2B). The fruits in the green stage presented a value of 110.73 N, a decrease of this value was observed when compared to the other maturation stages, with the fruits in the pre-mature stage presented average of 90.13 N and the mature fruits 86.71 N. Although the firmness of the fruits had reduced, the obtained values remained high, suggesting a higher resistance to physical damage, which may result in a longer life of the fruit after harvest. Similar results were verified by Silva et al. [19], who studied noni fruits at the same maturation stages, observed a reduction in firmness when compared to the green fruits with the ripe fruit, obtaining results of 128.41, 123.16 and 104.65 N for the maturation stages, green, "from time to time" and mature, respectively.

For the transverse length (Fig. 2C), it was observed that the fruits of the pre-mature stage had higher values, corresponding to 43.5 mm, the green and mature fruits had averages of 38.4 and 41.9 mm, respectively. At the longitudinal length (Fig. 2D) no significant difference was observed between maturation stages, however, it was possible to observe that the pre-mature fruits obtained larger values, corresponding to 128.4 mm, followed by the fruits in the green stage with 110.4 mm and of mature fruits with 90.91 mm. The results suggest that the fruits in the stage of green maturation were well developed, but still immature, the increase of the values observed in the longitudinal and transverse lengths in the pre-mature fruits, characterises fruits more physiologically developed. The noni fruits are oval shaped, a fact confirmed in this research, since the fruits had longer longitudinal lengths when compared to the transverse lengths. The results found in this work for the longitudinal and transverse length parameters differ from those reported by Nery et al. [18], who observed higher values for length, being 116.76 mm in the longitudinal and 56.66 mm in the transversal for mature noni fruits. These divergent results were probably due to the irregular development of the noni fruits in the plant.

Among the physical characteristics evaluated, the fresh mass correlated positively with the firmness (Table 1), due to the similar behaviour between the maturation stages, since, the progress of the maturation stage promoted reduction of these characteristics. The firmness was negatively correlated with the transverse

length, evidencing an opposite behaviour, which can be observed in the pre-mature stages where there is a decrease in firmness and an increase in longitudinal length. The other physical characteristics did not present a significant correlation with each other.

However, a significant difference was observed in maturity stages (L *) of the noni pulp (Fig. 3A). However, a higher mean was observed in the premature stage, corresponding to 69.99, followed by the green stage with 60.23 and mature with 49.56. In the shell (Fig. 3B) it was observed that this parameter behaved in an increasing manner, with the mature stage presented an average of 66.92, followed by the pre-mature with 62.44 and the mature with 55.63. The luminosity is related to the appearance of fruit, indicating how the fruit varies from black (0) to white (100), with noni fruits presenting values that vary around 50 to 60, leaving them in an intermediate range. It can be affirmed that the fruits of the noni, regardless of the stage of maturation, have a good appearance. Nery et al. [18] studying the brightness of the bark of noni fruits harvested at maturation stages similar to that of this research, observed a similar behaviour, where it was observed an increase with the maturation stage, obtaining 55.29 in the green, 58.97 in the time and 60.09 in the mature.

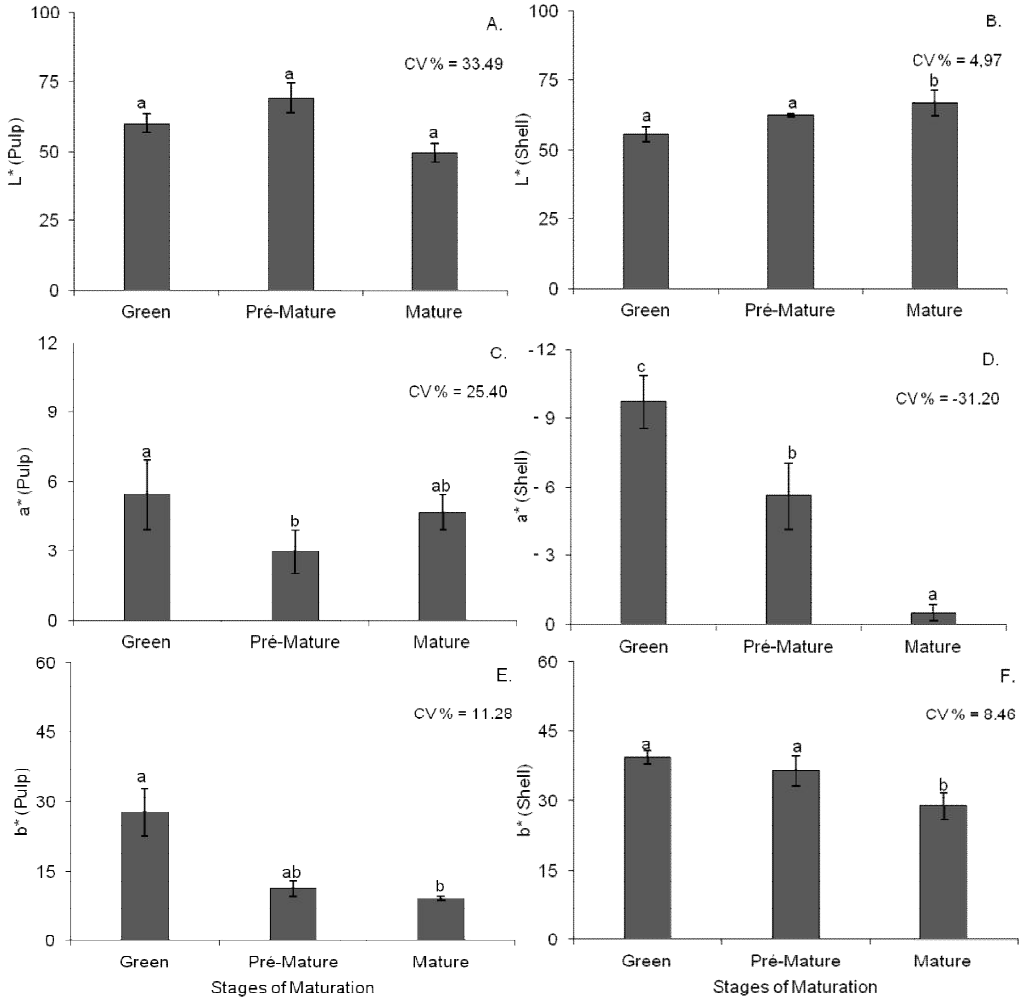

Fig. 3. Pulp brightness (A) and shell (B), coordinate a * of the pulp (C) and the shell (D), coordinate b * of the pulp (E) and the bark (F) of noni fruits harvested at three stages of maturation

The vertical bar represents the standard deviation of the means. (CV = coefficient of variation)

Table 1. Pearson correlation coefficients (r) between the physical characteristics of noni fruits harvested at three maturation stages

Characteristics	Fresh mass	Firmness	Comp. longitudinal
Firmeza	0.6176**	–	–
Comp. Longitudinal	0.2102^{ns}	0.1556 ^{ns}	–
Comp. Transversal	-0.4437^{ns}	-0.6165**	0.16257^{ns}

*^{ns} not significant; ** significant at the 5% probability level*

The coordinate a * represents the colour intensity with values ranging from -a (green colour) to + a (red colour). In the noni fruits, the values of the a * observed for the pulp (Fig. 3C) were positive, having obtained the green, pre-mature and mature fruits with averages of 5.43, 2.96 and 4.67, respectively. The positive values indicate the existence of the red colour in the noni pulp; however, the noni pulp presents a white colouration, the results obtained may have been influenced by the presence of seeds in the pulp, which has a brownish colouration, which explains the results positives.

However, the values of the coordinate a * for the noni shell (Fig. 3D) were negative, with -9.72 for the green fruits, -5.62 for the pre-mature and -0.51 for the mature ones. Negative values of the a * coordinate characterise the presence of the green colour in the fruit, a decrease was observed with the maturation stage, a behaviour that can be attributed to the degradation of chlorophyll (Fig. 5A), which is responsible for green colouration on the fruits. Nery et al. [18] also obtained negative results for a * coordinate in noni harvested at different stages of maturation, indicating predominance of green colour, however, variation was observed in the values being -11.80 stage "once", -8.96 in fruits mature and -5.15 in the greens, however, when observed the pre-mature and mature fruits a decrease is observed, which was also observed in this research.

The coordinate b * implies the variation of colours between yellow and blue, where + b corresponds to yellow and -b the colour blue. In the noni fruits, both pulp and bark presented positive values, 27.79 being observed in the fruit pulp of the green stage, 11.27 in the pre-mature and 9.07 in the mature. For the bark was determined 39.19 for fruits of the green stage, 36.45 for the pre-mature and 28.91 in the mature. Positive values indicate a tendency to yellowish colour in the noni fruits and a decrease of these values is observed with the advancement of maturation, this can be attributed to the degradation of the carotenoids (Fig. 5B). Nery et al. [18] when evaluating the coordinate b * observed an increase with the maturation stage corresponding to 33.20 for the green, 29.56 for the time and 30.17 for the mature, differently from the behaviour defined in this work, and the results may have been influenced by the variations in colouration during maturation.

Among the evaluated parameters, the b * coordinate of the pulp correlated negatively with the L * and the co-ordinate a * of the shell (Table 2), indicating that these presented different behaviours among maturation stages, which is evident in Fig. (Fig. 3B), with decreasing b * coordinates of the pulp (Fig. 3E) and a * of the bark (Fig. 3D), during the advancement of the maturation. The brightness L * of the bark showed a positive correlation with the a * coordinate of the bark, due to the similar behaviour presented with the maturation advance (Fig. 3A-3D), however, it was negatively correlated with b * of the bark, as well as the coordinate b * of the shell showed negative correlation with the a * coordinate of the shell, thanks to the distinct behaviour presented (Fig. 3A-3F-3D). The other parameters did not present a significant correlation between.

Table 2. Pearson correlation coefficients (r) between the L *, a *, and b * characteristics of the pulp and bark of noni fruits harvested at three maturation stages

Characteristics	L* Pulp	a* Pulp	b* Pulp	L* Shell	a* Shell
a* Pulp	-0.3100^{ns}	-	-	-	-
b* Pulp	0.0086^{ns}	0.4750^{ns}	-	-	-
L Shell	-0.1710^{ns}	-0.3786^{ns}	-0.7309**	-	-
a* Shell	-0.1267^{ns}	-0.2115^{ns}	-0.5516**	0.7640**	-
b* Shell	0.3026^{ns}	0.1035^{ns}	0.4659^{ns}	-0.7150**	-0.8813**

*^{ns} not significant; ** significant at the 5% probability level*

3.2 Physical-chemical Characterisation

It was observed a small reduction in pH values of the noni fruits with the advancement of the maturation stage (Fig. 4A), ranging from 4.67 for green fruits, 4.41 pre-mature fruits and 4.32 for mature fruits. The small variation of the pH values between the maturation stages, allowed to see an increasing effect of the H + ion concentration (Fig. 4B), where values of 21.04, 39.42 and 48.87 µM were observed in green, pre-mature and noni fruits. Mature, respectively. This small difference between the pH values resulted in an accumulation of more than 100% of the concentration of H + ions. Nery et al. [18] studying noni fruits grown in Fortaleza, Ceará, at maturation stages similar to those in this study, were very close to those found in this study, from 5.09 for green fruits, 4.92 for " for once" and 4.86 for mature ones.

Regarding the titratable acidity (Fig. 4C), no significant difference was observed between the maturation stages of the noni fruits studied. As a function of the maximum titratable acidity of 0.52% for the fruits of the green stage, it is possible to consider that the noni is a fruit of low acidity. Silva et al. [19] working with noni at a similar maturation stage, reported values of 0.21% for green fruits, 0.30% for intermediate fruit and 0.39% for fruits at mature maturity stage. The values observed by Silva et al. [19] were lower than those obtained in this study, which may have been caused by preharvest factors, where they have a decisive influence on the chemical quality of the plants [20].

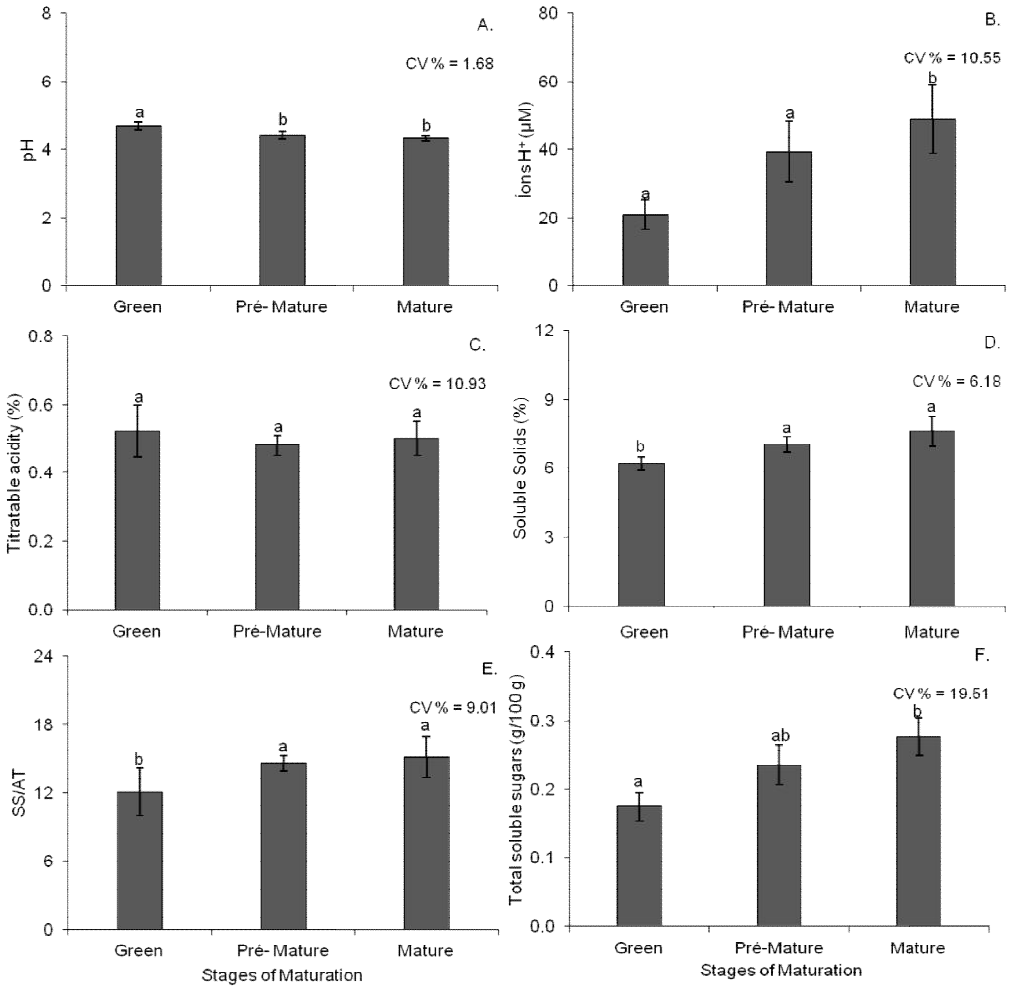

Fig. 4. pH (A), ions H +(B), titratable acidity (C), soluble solids (D), ratio SS/AT (E) and total soluble sugars (F) of noni fruits harvested at three maturation stages.

The vertical bar represents the standard deviation of the means. (CV = coefficient of variation)

For the soluble solids contents (Fig. 4D) there was a significant difference between maturation stages, with the mature fruit presented an average of 7.61%, followed by pre-mature stages with 7.63% and green with 6.05%, characterised by an increase with the maturation stages. Silva et al. [19] verified the accumulation of soluble solids equivalent to 4.83% for the green fruits, 8.33% for the fruits "of time" and 10.33% for the noni ripe fruits. In general, the solubility of the soluble solids tends to increase, due to the degradation of starch and subsequent synthesis of sugars, which can be evidenced by the increase of soluble sugars (Fig. 4F).

The SS/AT ratio resulted in a significant difference, with the noni fruits in the green stage averaging 12.11, the pre-mature 14.65 and the mature 15.18 (Fig. 4E). This difference is mainly due to the increase in the soluble solids content for the pre-mature and mature fruits, as well as the non-titratable acidity variation for the same fruits. Nery et al. [18] when working with the noni fruit obtained a value of 6.08 in the green stage, 12.78 for the maturation stage "once", and 19.30 for the ripe fruits. Already Silva et al. [19] found higher averages of 23.01 for green fruits, 27.80 for fruits "for" and 26.69 for mature fruits, the high ratio may be related to the higher results obtained for the variable soluble solids.

The soluble sugars presented an accumulation with the advancement of the maturation stage (Fig. 4F), with the green fruits presenting 2.32 g / 100 g, the pre-mature fruits 2.92 g / 100 g and the mature fruits 3.06 g / 100 g. Although it has not been determined in this work, it is believed that this increase can be due to the degradation of the starch and consequent synthesis of glucose, being the sugars contents a good indication of the maturation of the fruit. Costa et al. [21] in their study analysing the physical, chemical and phytochemical composition of the ripe noni seedless pulp reported content of 5.27% of total soluble sugars.

All the physical-chemical characteristics presented a positive correlation with each other (Table 3), however, a high positive correlation of pH with soluble solids and titratable acidity was observed, considering that they presented the similar behaviour with small variations between maturation stages. It was also verified a high positive correlation between SS / AT ratio and soluble solids, as expected since the soluble solids have a direct influence on the SS / AT ratio, the higher the soluble solids concentration the higher the SS / AT ratio.

3.3 Bioactive Compounds

A reduction in total chlorophyll values was observed with advancing maturation stage (Fig. 5A). The fruits in the green stage presented 0.37 mg / 100 g, followed by pre-mature fruits with 0.21 mg / 100 g and mature with 0.12 mg / 100 g. In view of the results, it was observed a degradation of this pigment with the advancement of the maturation stage, configuring the natural process of senescence of the fruit. These results are reinforced by the variation of the coordinate a * (Fig. 3C-3D), which already indicated degradation of the green colour of the fruits with the advancement of maturation.

The carotenoid content did not differ significantly, however, as the maturation stage progressed, with green fruits presenting 0.15 mg / 100 g, pre-mature 0.14 mg / 100 g and mature 0.08 mg / 100 g, reinforcing the results obtained for coordinate b * (Fig. 3E-3F), which already indicated a reduction of the yellow color of the fruits. Costa et al. [22] analysing the different parts of the mature noni fruit found carotenoid contents for the pulp of 3.90 mg / 100 g, for the bark 3.60 mg / 100 g and the seed of 1.06 mg / 100 g. Already Palioto et al. [23] studying the noni pulp reported the content of 0.45 mg / 100 g for carotenoids. Both studies quantified values superior to those found in this study, which may have been due to the environmental and cultural conditions in which the fruits were collected since they interfere in post-harvest quality [20].

Ascorbic acid (Fig. 5C) was found to be higher in mature fruits with a value of 216.87 mg / 100 g, followed by pre-mature fruits with 188.03 mg / 100 g and greens at 88.80 mg / 100 g, demonstrating that the maturation promotes an increase in ascorbic acid concentration. Yang et al. [24] also observed an increase in ascorbic acid levels with the maturation of the green stage to the hard white stage, which was evaluated in this study, however, there was a significant reduction in the ascorbic acid content with the ripening of the hard white stage fruit for soft white. Chan-Blanco et al. [25] observed the same behaviour, but the decrease of the contents was not significant. It is worth noting that in this study the fruit was not evaluated in the soft translucid white maturation stage since the fruit at this stage is already in an advanced state of senescence and its organoleptic properties are not pleasant.

Table 3. Pearson correlation coefficients (r) between the physicochemical characteristics of noni fruits harvested at three maturation stages

Characteristics	pH	Íons H^+	Soluble solids	Titratable acidity
Íons H^+	0.5176**	–	–	–
Soluble Solids	0.8933**	0.4285**	–	–
Titratable Acidity	0.9011**	0.5434**	0.7399**	–
SS/AT Ratio	0.7453**	0.3131**	0.9041**	0.4554**

*^{ns} not significant; ** significant at the 5% probability level*

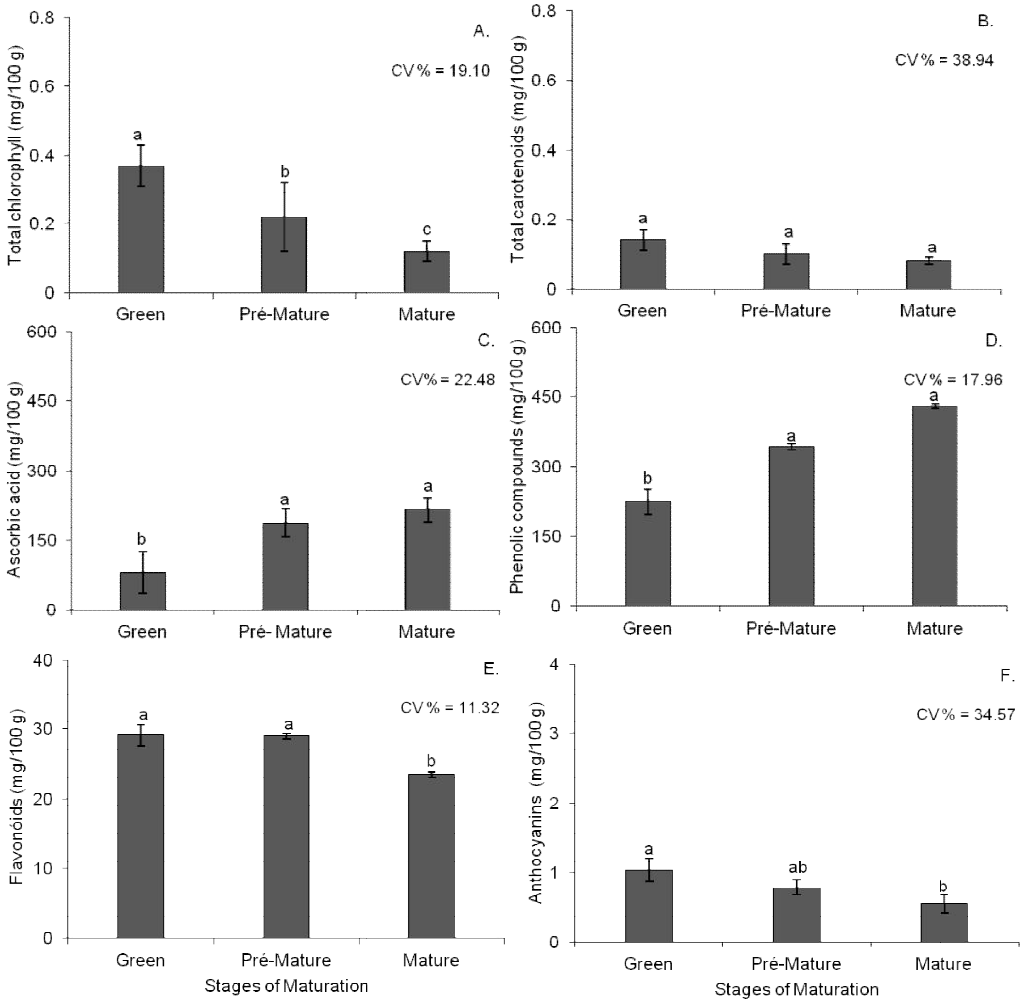

Fig. 5. Total chlorophyll (A), total carotenoids (B), ascorbic acid (C), total phenolic compounds (D), flavonoids (E) and anthocyanins (F) of noni fruits harvested at three maturation stages

The vertical bar represents the standard deviation of the means. (CV = coefficient of variation)

The fruits in the mature stage showed high contents of phenolic compounds, corresponding to 430.02 mg / 100 g, pre-mature and green fruits presented 342.24 and 225.70 mg / 100 g, respectively (Fig. 5D). Yang et al. [24] observed similar behaviour, in which ripe fruits presented higher levels of phenolic compounds, which characterises the synthesis of this with the advancement of maturation in noni fruits. The high content of phenolic compounds in the mature noni determined in this research reinforces the practice by modern healers who make use of mature noni as a remedy due to their antioxidant potential Yang et al. [24].

Table 4. Pearson correlation coefficients (r) between the bioactive characteristics of noni fruits harvested at three maturation stages

Characteristics	Ascorbic acid	Chlorophyll	Carotenoids	C. Phenolic	Flavonoids
Chlorophyll	-0.9103**	–	–	–	–
Carotenoids	-0.4685 ns	0.5217**	–	–	–
C. Phenolic	0.8927**	-0.8506**	-0.3764 ns	–	–
Flavonoids	-0.4491 ns	0.5920**	0.6665**	-0.5354**	–
Anthocyanins	-0.7212**	0.6913**	0.4678 ns	-0.6600**	0.6107**

*ns not significant; ** significant at the 5% probability level*

The results obtained for flavonoids (Fig. 5E) presented a significant variation between the maturation stages, a mean of 29.12 mg / 100 g in the pre-mature fruits 29.00 mg / 100 g and the mature fruits 23.53 mg / 100 g, being verified reduction with the advancement of maturation. Palioto et al. [23] quantified 13.01 mg / 100 g of flavonoids in noni pulp, a lower value than that found in this work. The highest values found in this work may have been caused by the use of the bark and seeds to obtain the extract since Palioto et al. [23] analysed only the pulp.

As for the noni anthocyanins content in this study (Fig. 5F), a behaviour similar to that observed for flavonoids was observed, with reduction with maturation advance, but with levels varying from 1.04 mg / 100 g for the fruits of the stage 0.77 mg / 100 g in the pre-mature and 0.55 mg / 100 g in the mature. The similar behaviour occurring for both was already expected since the anthocyanins are pigments belonging to the flavonoid group. These are responsible for assigning a wide variety of colours to fruits and leaves, however, their main function is to protect plants against ultraviolet light, thus avoiding the production of free radicals [26]. Palioto et al. [23] found a content of 1.39 mg / 100 g in the noni ripe pulp, higher than that found for ripe fruits in this work, the decrease may have been due to the conditions of cultivation and management of the plant, since several factors, such as climate, soil, nutrient availability and even the amount of light on the plant influences the availability of this and other compounds [20].

It can be verified that ascorbic acid showed a high negative correlation with chlorophyll and anthocyanins (Table 4), being observed the accumulation of ascorbic acid and the reduction of the others during the maturation advance. A high positive correlation of ascorbic acid with phenolic compounds was also observed, since the accumulation of these acids, especially at the mature stage, was evident. Chlorophyll was positively correlated with carotenoids, flavonoids, and anthocyanins, and all these parameters were observed to decrease during maturation. It was also verified the negative correlation of chlorophyll with phenolic compounds, being observed the accumulation of phenolic compounds and degradation of chlorophyll during the maturation of noni fruits.

There was also a positive correlation between carotenoids and flavonoids, both of which were reduced at the mature stage. The phenolic compounds were negatively correlated with flavonoids and anthocyanins, with phenolic accumulation being verified and others being reduced. The positive correlation of flavonoids with anthocyanins was also verified, as both decreased with the advancement of maturation. The others did not present a significant correlation with each other.

4. CONCLUSIONS

Irregular growth of the noni fruits is confirmed since the fruits of the green maturation stage presented higher values of fresh mass when compared to the other stages of maturation. It was also possible to observe that the maturation stage affects the physicochemical characteristics of noni, in particular, the concentration of H + ions, SS / AT ratio and total soluble sugars, which can interfere in the final quality of the fruits, The high levels of ascorbic acid and phenolic compounds estimated in the noni fruits, especially at the mature stage, indicate its antioxidant potential, suggesting that its use is feasible for food production with functional character, and it is necessary to develop future research for confirmation of its antioxidant capacity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. West BJ, Deng S, Jensen CJ. Nutrient and phytochemical analyses of processed noni puree. Food Research International. 2011; 44(7):2295-2301.
2. Nelson SC. Species profiles for pacific island agroforestry: *Morinda citrifolia* L.; 2003.
(Accessed on October 12, 2018)
Available:https://www.doc-developpement-durable.org/file/ArbresFruitiers/FICHES_ARBRES/Morinda%20citrifolianoni/Morinda%20citrifolia_noni.pdf
3. Barbosa AF, Costa ICM, Zucolotto SM, Giordani RB. *Morinda citrifolia*: Facts and risks on the use of noni. Fitos Magazine, Rio de Janeiro. 2017;11(2):119-249.
DOI: 10.5935/2446-4775.20170027
4. Matoso LML, Melo CCR, Menezes, LMCS, Oliveira LE, Oliveira KKD. Characteristics and use of noni (*Morinda citrifolia*). Electronic Journal of Fainor, Vitória da Conquista. 2013;6(1):42-50.
(Accessed on January 5, 2018)
Available:http://srv02.fainor.com.br/revista/index.php/memorias/article/view/178/137
5. Singh DR. *Morinda citrifolia* L. (Noni): A review of the scientific validation for its nutritional and therapeutic properties. Journal of Diabetes and Endocrinoogy. 2012;3(6):77–91.
DOI: 10.5897/JDE10.006
6. Iloki Assanga SB, Lewis-lujan LM, Rivera-Castaneda EG, Gil-Salido AA, Acosta-Silva AL, Meza-Cueto CY, Rubio-Pino JL. Effect of maturity and harvest season on antioxidante activity, phenolic compounds and ascorbic acid of *Morinda citrifolia* L. (noni) grown in Mexico (with track change). African Jounal Biotechnology. 2013;12(29): 4630–4639.
Available:https://doi.org/10.5897/AJB12.1881
7. Tombolato AF, Barbosa W, Hiroce R. Noni: Medicinal fruit in introduction and acclimatization in Brazil. Technical information: The agronomic, Campinas. 2005;49:7-11.
8. Kuskoski EM, Asuero AG, Morales MT, Fett R. Wild tropical fruits and frozen fruit pulps: Antioxidant activity, polyphenols and anthocyanins. Rural Science. 2006;36: 1283-1287.
Available:http://dx.doi.org/10.1590/S0103-84782006000400037.
9. Flores-Cantillano RF, Madail JCM, Mattos MLT. Food market: World trend. Agricultural Report, Belo Horizonte. 2001; 22(213):79-84.
10. Farias VFS. Evaluation of development, quality and antioxidant capacity in palm shoots (*Opuntia sp*.) For human consumption. 74 f. Federal University of Campina Grande: Postgraduate Program in Agroindustrial Systems; 2013.
11. Minolta. Precise color communication - color control from perception to instrumentation. Japan: Minolta Co., Ltd., 1998;59.
12. Instituto Adolfo Lutz. Analytical standards of the Adolfo Lutz institute: Chemical and physical methods for food analysis. 4th ed. São Paulo: IAL; 2008.
13. Yemm EW, Willis AJ. The estimation of Carbohydrates in plant extracts by anthrone. Iochemical Journal. 1954;57: 508-515.
14. Lichtenthaler HK. Chorophylls and carotenoides: Pigmentos of photosynthetic biomembranes. In: Packe L, Douce R. (Ed). Methods in enzimology. Academic Press, London, 1987;148:350-382.
Available:https://doi.org/10.1016/0076-6879(87)48036-1
15. Waterhouse A. Folin-ciacalteau micro method for total phenol in wine. American Journal of Enology and Viticulture. 2016;3-5.
16. Francis FJ. Analysis of anthocyanins. In: Markakis P. (Ed). Anthocyanins as food colors. Academic Press, New York. 1982; 81-207.
17. Barbosa JC, Maldonado Junior W. Agro estat - statistical analysis system for Agronomic Assays. Version 1.1.0.712. Jaboticabal, São Paulo, Brasil; 2014.
18. Nery KA, Araújo RO, Braga TR, Oliveira MMT, Torres LBV, Silva LR. Physical and physical-chemical characterization of noni fruits (*Morinda citrifolia L*.) cultivated in Fortaleza-CE. Cultivating the Knowledge Magazine, Cascavel-PR. 2013;6(1):17-24.
19. Silva LR, Medeiros PVQ, Leite GA, Silva KJP, Mendonça V, Silva GG. Characterization of noni fruit (*Morinda citrifolia* L.). Cuban Journal of Medicinal Plants, Cuba: Havana. 2012;17(1):93-100.
(Accessed on January 15, 2018)
Available:http://scielo.sld.cu/pdf/pla/v17n1/pla10112.pdf.
20. Mattiuz B. Pre-harvest factors influence the final quality of the products. Agricultural View. 2007;7:19–21.
21. Costa W, Faria S, Bett SC, Garcia C, Silva A. Physical-chemical characterization and

preliminary phytochemical analysis of the noni fruit (*Morinda citrifolia* L.) produced in the city of Cuiabá - MT. Brazilian Journal of Agroindustrial Technology. 2014;08:1208–1215.
DOI: 10.3895/S1981-36862014000100006

22. Costa BA, Oliveira AMC, Silva AMO, Mancini-Filho J, Lima A. Antioxidant activity of the pulp, bark and seeds of the noni (*Morinda citrifolia* Linn). Brazilian Journal of Fruticulture, Jaboticabal. 2013; 35(2):345-354.
Available:http://dx.doi.org/10.1590/S0100-29452013000200003.

23. Palioto GF, Silva CFG, Mendes MP, Almeida VV, Rocha CLMSC, Tonin LTD. Centesimal composition, bioactive compounds and antioxidant activity of *Morinda citrifolia* Linn (noni) fruits grown in Paraná. Brazilian Journal of Medicinal Plants, Campinas. 2015;17(1):59-66.
Available:http://dx.doi.org/10.1590/1983-084X/13_066

24. Yang J, Gadi R, Thomson T. Antioxidant capacity, total phenols, and ascorbic acid content of noni *(Morinda citrifolia)* fruits and leaves at various stages of maturity. Micronesica. 2011;41(2):167–176.
(Accessed on January 10, 2018)
Available:http://www.micronesica.org/sites/default/files/11_yang_et_al_pp_167-176.pdf

25. Chan-Blanco Y, Vaillant F, Pérez AM, Marie-Pierre B, Zúñiga C, Brat P. The ripening and aging of noni fruits (*Morinda citrifolia* L.): Microbiological floral and antioxidant compunds. Journal of Science and Food Agriculture. 2007;87:710–6.
Available:https://doi.org/10.1002/jsfa.2894

26. Malacrida CR, Motta S. Anthocyanins in grape juice: Composition and stability. Food Processing Research Center Bulletin. 2006;24(1):59-82.
Available:http://dx.doi.org/10.5380/cep.v24i1.5294

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/26934