Maturation indexes and physiological quality of seeds and fruits of *Morinda citrifolia* L.

Índices de maturação e qualidade fisiológica de sementes e frutos de *Morinda citrifolia* L.

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ABSTRACT
The seeds of Morinda citrifolia L. present unevenness and delay in germination in relation to other fruit trees. Knowledge about the physiological quality of seeds is extremely relevant for the production of seedlings and propagation of the species. Thus, the objective was to study maturation indices and the physiological quality of seeds and fruits of M. citrifolia. Seeds from freshly picked fruits, fruits harvested after seven days of maturation and freshly dropped fruits were used. The extracted and processed seeds were submitted to the following pre-germination treatments: GA₃, KNO₃ and H₂O. The following were analyzed: fruit length and diameter, seed length, width and thickness, number of seeds per fruit, average number of seeds per kg, weight of 1000 seeds, germination, germination speed index, shoot and root length, seedling dry mass and percentage of normal seedlings. The experimental design used was completely randomized, with three stages of fruit maturation and six treatments, with four replications of 25 seeds. M. citrifolia seeds do not show tegumentary dormancy. The seeds of freshly harvested fruits and fruits harvested after seven days of maturation do not need pre-germination treatments. GA₃ promotes greater germination in seeds of fruits harvested from the ground. Fruits that have just fallen to the ground have a higher content of soluble solids and a higher content of acidity. The storage of fruit in a refrigerator for a week provides the maintenance of texture characteristics, such as hardness, adhesiveness, elasticity and gumminess. Fruits with greater hardness have higher physiological seed quality.

Keywords: force, germination, noni, soluble solids.

RESUMO
As sementes de Morinda citrifolia L. apresentam desuniformidade e atraso na germinação em relação a outras frutíferas. O conhecimento sobre a qualidade fisiológica das sementes é extremamente relevante para a produção de mudas e propagação da espécie. Assim, o objetivo foi estudar os índices de maturação e a qualidade fisiológica de sementes e frutos de M. citrifolia. Foram utilizadas sementes de frutos recém-colhidos, frutos colhidos após sete dias de maturação e frutos recém-derrubados. As sementes extraídas e processadas foram submetidas aos seguintes tratamentos pré-germinativos: GA₃, KNO₃ e H₂O. Foram analisados: comprimento e diâmetro do fruto, comprimento, largura e espessura da semente, número de sementes por fruto, número médio de sementes por kg, peso de 1.000 sementes, germinação, índice de velocidade de germinação, comprimento do broto e da raiz, massa seca da plântula e porcentagem de plântulas normais. O delineamento experimental utilizado foi o inteiramente casualizado, com três estágios de maturação dos frutos e seis tratamentos, com quatro repetições de 25 sementes. As sementes de M. citrifolia não apresentam dormência tegumentar. As sementes de frutos recém-colhidos e de frutos colhidos após sete dias de maturação não necessitam de tratamentos pré-germinativos. O GA₃ promove maior germinação em sementes de frutos colhidos do chão. As frutas que acabaram de cair no chão têm maior teor de sólidos solúveis e maior teor de acidez. O armazenamento de frutas em geladeira por uma semana proporciona a manutenção das características de textura, como dureza, adesividade, elasticidade e gumosidade. Os frutos com maior dureza apresentam maior qualidade fisiológica da semente.

Palavras-chave: força, germinação, noni, sólidos solúveis.
1 INTRODUCTION

*Morinda citrifolia* L., the Indian blackberry, is a fruit tree of the Rubiaceae (Rubiioideae) family. Popularly known as noni, it is an endemic species from Southeast Asia, Indonesia, and Polynesia. The adult tree is relatively short, reaching 3 to 10 m in height. It is composed of wide and green leaves, its flowering is abundant, expanding throughout the canopy, and fruiting occurs throughout the year, producing infructescence-like fruits containing abundant seeds (WANG et al., 2002; BELTRÃO et al., 2014). It stands out among the main medicinal plants, has been used in Polynesia for more than 2,000 years, and has aroused great interest by researchers due to the presence of more than one hundred metabolites, whose main families of molecules are phenolic compounds, organic acids and alkaloids, and terpenes and steroids, such as coumarin, which are found in all parts of the plant, such as leaves, fruits, and roots (WANG, 2002; SOUZA et al., 2011; ILOKI ASSANGA et al., 2013; BRASIL, 2014; KRISHNAIAH et al., 2015; PALIOTO et al., 2015; SIMÕES, 2017).

Secondary metabolites originate from glucose metabolism by two main intermediates: (1) shikimic acid, a precursor of hydrolyzable alkaloid tannins derived from aromatic amino acids and cinnamic acid; and (2) acetate, from which aliphatic amino acids and alkaloids originate: terpenoids, steroids, fatty acids, and triglycerides. Further, derivatives of a combination of a shikimic acid unit and one or more acetate units or derivatives thereof also exist, such as (1) anthraquinones and flavonoids, acting as phenolic compounds important in the pigmentation and protection of plants against ultraviolet rays, insects, fungi, bacteria, and viruses, and (2) condensed and hydrolyzed tannins, which act as antioxidants, anti-inflammatory, antimutagenic, and anticarcinogenic compounds, which are beneficial to human health (SIMONS et al., 2017; TAIZ et al., 2017; MAQSOOD et al., 2020; HIRASAWA et al., 2021). It is estimated that approximately 50% of the native species of Brazil have medicinal properties and are widely disseminated by the Brazilian population. Cultivated or not, these medicinal plant species are used for therapeutic and phytotherapeutic purposes owing to the products obtained from the plants or their parts, having prophylactic, curative, or palliative purposes useful to modern medicine and traditional herbal medicine (BRASIL, 2014). Therefore, there has been a constant growth in the use of herbal medicines, including *M. citrifolia*, in Brazil (KABIR et al., 2014; LUCAS et al., 2016).
In addition to the presence of damnacanthal anthraquinone, which exhibits antitumorigenic activity in cancer cells, it also exhibits hepatoprotective, human colorectal, and vascular protective activities (NUALSANIT et al., 2012; CHONG et al., 2018; CHONG et al., 2019; WANG et al., 2020; HIRASAWA et al., 2021), and insecticidal, antifungal, antibacterial, and antimicrobial properties in animals and plants (BARANI et al., 2014; MOMPIÉ et al., 2014; DIVIA et al., 2018; RAJIVGANDHI et al., 2020; BARROS et al., 2021). Therefore, studies suggest its preventive action in the formation and proliferation of tumors and conclude that noni extract has an increasing effect on gingival-derived mesenchymal stem cells, increasing cell viability and osteogenic differentiation in stem cells, in which significantly higher values of cell viability were observed at 100 ng mL\(^{-1}\) compared to the control (SONG et al., 2022).

Given the above and the numerous active principles identified, *M. citrifolia* has high commercial interest (SOUZA et al., 2021), requiring studies involving its propagation for seedling production, which is seminiferous and must have genetic, sanitary, physical, and physiological attributes that involve germination and vigor, which are associated with the origin and maturation process of the seed. Its development begins in ontogenic stages, which culminate in the maximum accumulation of nutrients, reduction in water content, dormancy, a series of morphophysiological changes, maximum accumulation of dry mass, germination, and vigor (DELOUCHE, 2002; CARVALHO; NAKAGAWA, 2012; MARCOS FILHO, 2016), as observed in *Paeonia lactiflora* Pall. (MENG et al., 2021) and *Crambe abyssinica* Hochst (AMARO et al., 2021).

The quality of the seed in the fruit maturation phase is influenced by environmental factors, both biotic and abiotic, which involve genetic, physiological, physical, sanitary factors, and crop management; these factors influence imbibition, germination, emergence, and formation of normal seedlings (DELOUCHE, 2002; CARVALHO; NAKAGAWA, 2012; SANTOS et al., 2015; BELMONT, 2017). Therefore, seeds with high physiological quality provide greater plant establishment, population, yield, and productivity, affecting the final crop production (SANTOS et al., 2015; CARDOSO et al., 2021; BAGATELI et al., 2022). The fruit maturation stage and place of harvest are crucial for fruit quality and for obtaining seeds of high physiological quality, as observed in *Capsicum baccatum* L. (PEREIRA et al., 2014) and *Passiflora* spp. (MACIEL et al., 2018).
Thus, the objective of this study was to determine the maturation indices and physiological quality of the seeds and fruits of *M. citrifolia*.

2 MATERIAL AND METHODS

The study was conducted at the Seed Analysis Laboratory (LAS) of the Center for Agricultural Sciences and Engineering at the Federal University of Espírito Santo (CCAE-UFES) in the city of Alegre-ES. Fruits were harvested from mother trees at Fazenda Ponte da Braúna, located in the district of Rive, Alegre, state of Espírito Santo (20° 45' S and 41° 29' W; altitude 138 m) (INMET, 2022). According to the international classification of Köppen, the climate of the region is of the type “Cwa,” that is, tropical hot humid, with hot and rainy summers, cold and dry winters, and average annual precipitation of 1341 mm. The fruits were harvested at three maturation indices: freshly picked fruits from the matrices (FPF), ripe fruits harvested and stored in a refrigerator at 3 ± 1 °C for seven days (FSR), and freshly fallen fruits (FFF).

Fruit length (FL), fruit diameter (FD), seed length (SL), seed width (SW), and seed thickness (ST) were measured with the aid of a digital caliper. The number of seeds per fruit (NS), average number of seeds per kg (NK), and weight of 1000 seeds (WS) were measured on an analytical balance (0.0001 g) for freshly picked fruits (FPF), fruits stored in a refrigerator for seven days (FSR), and freshly fallen fruits (FFF).

The seeds were extracted with the aid of a sterilized spoon, processed, and the pulp removed with quenched lime over a sieve. Then, the seeds were washed in running water and kept on germitest paper in the shade for 24 h at room temperature in the LAS. The experimental design was completely randomized, using seeds from fruits in the three stages of maturation and seven treatments: untreated seeds (control); seeds treated with gibberellic acid (GA₃) at a concentration of 50 mg L⁻¹ for 24 h, potassium nitrate (KNO₃) at a concentration of 2 g L⁻¹ for 24 h, and H₂O at 70; 80; 90, and 100 °C for one minute. The variables analyzed were as follows:

Germination: The seeds were sown in paper rolls (RP), made with overlapping sheets of germitest paper, covered with a third sheet, moistened with distilled water at a proportion of 2.5 × the mass of dry paper, and kept in transparent plastic bags to avoid the loss of water by evaporation. The plastic bags were then placed in a germination chamber type BOD (biochemical oxygen demand), regulated at an alternating temperature of 20-30 °C (16-8 h). The evaluations
were performed daily for a period of two months, the percentage of normal seedlings were computed (BRASIL, 2009), and the results were expressed as percentage of germination.

The germination speed index (GSI) was determined concomitantly with the germination test, computed daily until the 60th day. GSI was obtained from the number of seeds that presented primary root protrusion ≥ 2 mm (MAGUIRE, 1962).

Shoot length was determined 60 days after sowing, with the aid of a millimeter ruler, by measuring the length between the stem and apex of the last leaf of each seedling, and the result was expressed in cm seedling\(^{-1}\).

Root length was determined 60 days after sowing, with the aid of a millimeter ruler, and measured from the plant neck to the tip of the largest root, and the results were expressed in cm plantula\(^{-1}\).

Seedling dry mass was determined after 60 days of sowing using an analytical balance (0.0001 g). The seedlings were placed in Kraft paper bags and kept in a convection oven at 72 °C for 72 h (constant mass), and the results were expressed in mg seedling\(^{-1}\).

The percentage of normal seedlings was determined based on the number of seedlings with normally developed roots and shoots (BRASIL, 2009).

Fruits from different maturation stages were subjected to chemical analysis: soluble solids (SS) and titratable acidity (AT). Acidity was determined by volumetry using a phenolphthalein indicator. For each degree of maturation, 12 fruits were used with three replicates of four fruits, from which 5–10 g were taken from the homogenized samples for analysis. Subsequently, 100 mL of water and 0.3 mL of phenolphthalein solution were added to each sample. The sample was titrated with 0.1 M sodium hydroxide (NaOH) under constant stirring. Soluble solids (°Brix) analyses were performed with the aid of a refractometer, using three drops of each sample for analysis, according to the manual of Instituto Adolfo Lutz (1985).

In the texture analysis, the parameters were determined with the aid of the Brookfield CT3 texturometer, using the TA9 needle probe, with a test speed of 0.5 mm s\(^{-1}\) for FPF and 1 mm s\(^{-1}\) for FFF and FCC. The target drilling distance was set at 3 mm.

All statistical analyses were performed using the R software (R CORE TEAM, 2021). In experiment 1, a 3 × 7 factorial (fruit origin × seed treatments) design was adopted and tested, with four replications of 25 seeds, and the means were compared using the F test at a 5% probability level and the Scott-Knott test (p ≤ 5%). In Experiment 2, Tukey’s test was used (p ≤
After analyzing the fruits and seeds, Pearson’s correlation was performed at a level of 1% and 5% probability using the F test to determine the relationship between the variables studied.

3 RESULTS

*M. citrifolia* fruit lengths ranged between 91 and 108 mm, and FSR and FFF had the highest means (103 and 108 mm, respectively). FSR had the largest diameter (67.4 mm) (Table 1).

Regarding seed physical characteristics, there was no significant difference in mean length and width between the indices of maturation of the fruits, with the length varying from 8.6 to 9.0 mm and the width from 4.0 to 4.6 mm. However, the seeds from FFF showed a lower thickness (2.0 mm), with no significant difference between the seeds from FPF and FSR (3.0 and 3.2 mm, respectively).

The 1000-seed weight of FPF, FSR, and FFF showed no significant difference (31.98, 32.38, and 32.12 g, respectively). In fact, 1 kg *M. citrifolia* seeds from FPS, FSR, and FFF represented approximately 31,269, 30,883, and 31,133 seeds, respectively. The noni fruit is a synchrope and 247–265 seeds can be obtained from each fruit (Table 1).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>FPF</th>
<th>FSR</th>
<th>FFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>FL (mm)</td>
<td>91 b</td>
<td>103 ab</td>
<td>108 a</td>
</tr>
<tr>
<td>FD (mm)</td>
<td>56.2 b</td>
<td>67.4 a</td>
<td>59.6 b</td>
</tr>
<tr>
<td>SL (mm)</td>
<td>8.6 a</td>
<td>9.0 a</td>
<td>9.0 a</td>
</tr>
<tr>
<td>SW (mm)</td>
<td>4.6 a</td>
<td>4.2 a</td>
<td>4.0 a</td>
</tr>
<tr>
<td>ST (mm)</td>
<td>3.0 a</td>
<td>3.2 a</td>
<td>2.0 b</td>
</tr>
<tr>
<td>NS</td>
<td>247 b</td>
<td>265 a</td>
<td>258 ab</td>
</tr>
<tr>
<td>NK</td>
<td>31.269 a</td>
<td>30.883 a</td>
<td>31.133 a</td>
</tr>
<tr>
<td>WS (g)</td>
<td>31.98 a</td>
<td>32.38 a</td>
<td>32.12 a</td>
</tr>
</tbody>
</table>

Means followed by the same letter, lowercase in the lines, do not differ from each other at a level of 5%, by Tukey's test.

Source: Author

In the seed germination analysis (Table 2), there was a significant difference in the fruit harvest phase. The FPF and FSR seeds had the highest germination rates (82 and 62%, respectively), whereas the FFF seeds had the lowest value (6%).
Regarding the seeds treated with KNO$_3$, water at 70 °C, and the control, the highest means were obtained for FPF seeds, differing significantly from those originating from FSR and FFF. In the case of seeds treated with water at 80 °C and 90 °C, the FSR seeds showed a higher percentage of germination. The seeds treated with water at 100 °C, regardless of the stage of fruit maturation, did not germinate (Table 2), suggesting that temperature was lethal to the seeds.

Considering seeds from FPF, the highest mean (82%) corresponded to those that were not subjected to treatment (control), a behavior similar to that observed in seeds from FSR (62%), whereas FFF seeds showed a germination percentage of 6%. However, in the seeds from FFF, the highest mean germination was observed in seeds treated with GA$_3$ (12%) (Table 2), and the highest mean shoot and root lengths of the seedlings were observed (Table 3).

Considering seed vigor through GSI (Table 2), in the treatment with KNO$_3$ and in the control, the FPF seeds presented higher mean GSI (0.78 and 0.36, respectively). However, in the treatment of seeds with GA$_3$, the seeds of FSR and FPF had higher mean GSI (0.18 and 0.17, respectively), while the seed of FFF had the lowest mean GSI (0.11). In the treatment with H$_2$O at 70 °C and 80 °C, the FSR seeds presented higher mean GSI, differing from the FPF and FFF seeds. Regarding the H$_2$O at 90 °C treatment, only the FSR seeds presented GSI, that is, the other seeds did not germinate. Seeds were treated with H$_2$O at 100 °C, regardless of the fruit maturation stage, as there was no germination, and the GSI was equal to zero.

In FPF and FSR seeds, the treatment that presented the highest mean GSI (0.78 and 0.56, respectively) was the control. For FFF seeds, the control (0.13) and seeds treated with GA$_3$ (0.11) presented the highest means.

Table 2. Germination (G) and germination speed index (GSI) of M. citrifolia seeds from freshly picked fruits (FPF), fruits stored in a refrigerator for seven days (FSR) and freshly fallen fruits (FFF), subjected to different pre-germination treatments.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>G (%)</th>
<th>GSI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FPF</td>
<td>FSR</td>
</tr>
<tr>
<td>Control</td>
<td>82 aA</td>
<td>62 aB</td>
</tr>
<tr>
<td>GA$_3$</td>
<td>30 cA</td>
<td>30 dA</td>
</tr>
<tr>
<td>KNO$_3$</td>
<td>58 bA</td>
<td>42 bB</td>
</tr>
<tr>
<td>H$_2$O 70 °C</td>
<td>58 bA</td>
<td>36 cB</td>
</tr>
<tr>
<td>H$_2$O 80 °C</td>
<td>4 dB</td>
<td>12 eA</td>
</tr>
<tr>
<td>H$_2$O 90 °C</td>
<td>0 eA</td>
<td>4 FA</td>
</tr>
<tr>
<td>H$_2$O 100 °C</td>
<td>0 eA</td>
<td>0 dA</td>
</tr>
<tr>
<td>CV (%)</td>
<td>12.94</td>
<td>19.19</td>
</tr>
</tbody>
</table>

Means followed by the same letter, lowercase in the column and uppercase in the row, do not differ from each other at a level of 5%, according to the Scott Knott test.

Source: Author
There was no significant difference in shoot length (Table 3) of seedlings treated with GA\textsubscript{3} and H\textsubscript{2}O at 80 °C, regardless of the fruit maturation stage. The seeds of FPF and FSR presented higher means of aerial part length when treated with KNO\textsubscript{3} and H\textsubscript{2}O at 70 °C, whereas the seeds treated with H\textsubscript{2}O at 90 °C presented values of these variables only with FSR, mainly because they were the only ones that germinated and showed normal seedlings. In the treatment of H\textsubscript{2}O at 100 °C, there was no seed germination. However, in relation to the control, the highest mean shoot length was observed in FSR seeds.

In FPF and FFF seeds treated with GA\textsubscript{3}, the SL presented the highest mean (4.4 cm and 4.3 cm, respectively) in relation to the other treatments. Seeds treated with GA\textsubscript{3} and H\textsubscript{2}O at 90 °C had the highest means (4.1 cm and 4.0 cm, respectively).

In the treatments with GA\textsubscript{3} (Table 3), the FFF seeds showed the highest mean root length. The treatments with KNO\textsubscript{3}, H\textsubscript{2}O at 70 °C, and H\textsubscript{2}O at 80 °C showed no statistical difference in relation to root length, regardless of fruit maturation stage. In the treatment with H\textsubscript{2}O at 90 °C, the seeds of FSR had greater growth and root length, and it was at this same maturation stage that seeds showed germination, while in the seeds treated with H\textsubscript{2}O at 100 °C there was no germination and the seeds presented deteriorated.

The FPF seeds had the highest mean root length (0.9 cm) when they were not subjected to any treatment (control). The FSR seeds presented the highest mean root length in the control (0.7 cm) and when submitted to H\textsubscript{2}O at 70 °C (0.6 cm). For FFF seeds, the highest means were obtained when the seeds were treated with GA\textsubscript{3} (0.9 cm).

Table 3. Shoot length (SL) and root length (RL) of seedlings from seeds of *M. citrifolia* from freshly picked fruits (FPF), fruits stored in a refrigerator for seven days (FSR) and freshly fallen fruits (FFF), subjected to different pre-germination treatments.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>SL (cm)</th>
<th>RL (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FPF</td>
<td>FSR</td>
</tr>
<tr>
<td>Control</td>
<td>2.5 cB</td>
<td>3.4 bA</td>
</tr>
<tr>
<td>GA\textsubscript{3}</td>
<td>4.4 aA</td>
<td>4.1 aA</td>
</tr>
<tr>
<td>KNO\textsubscript{3}</td>
<td>3.7 bA</td>
<td>3.5 bA</td>
</tr>
<tr>
<td>H\textsubscript{2}O 70 °C</td>
<td>3.4 bA</td>
<td>3.4 bA</td>
</tr>
<tr>
<td>H\textsubscript{2}O 80 °C</td>
<td>2.7 cA</td>
<td>2.6 cA</td>
</tr>
<tr>
<td>H\textsubscript{2}O 90 °C</td>
<td>0.0 dB</td>
<td>0.0 dB</td>
</tr>
<tr>
<td>H\textsubscript{2}O 100 °C</td>
<td>0.0 dA</td>
<td>0.0 dA</td>
</tr>
<tr>
<td>CV (%)</td>
<td>12.26</td>
<td>15.98</td>
</tr>
</tbody>
</table>

Means followed by the same letter, lowercase in the column and uppercase in the row, do not differ from each other at a level of 5%, according to the Scott Knott test.

Source: Author
Seeds treated with GA\textsubscript{3}, KNO\textsubscript{3}, H\textsubscript{2}O at 70 °C, and untreated seeds (control) (Table 4) presented higher mean seedling dry mass when originating from FFF. In the treatment with H\textsubscript{2}O at 80 °C, the FPF seeds showed the highest means. The FSR seeds treated with H\textsubscript{2}O at 90 °C showed higher means than the FPF and FFF seeds. However, in the treatment with H\textsubscript{2}O at 100 °C, the seeds did not germinate.

The FPF seeds showed a higher average dry mass when subjected to H\textsubscript{2}O at 80 °C (7.00 mg). In the case of FSR seeds, the treatment with H\textsubscript{2}O at 90 °C had the highest average (6.00 mg). Regarding the FFF seeds, the treatments with KNO\textsubscript{3}, H\textsubscript{2}O at 70 °C, and H\textsubscript{2}O at 80 °C were the ones that presented the highest values of dry mass (6.12 mg, 5.88 mg, and 6.00 mg, respectively).

The FSR and FPF seeds (Table 4) treated with GA\textsubscript{3} had the highest percentage of normal seedlings. In the treatments with KNO\textsubscript{3}, H\textsubscript{2}O at 70 °C, and the control, the FPF seeds showed the highest percentage of normal seedlings, significantly differing from the others. FSR seeds treated with H\textsubscript{2}O at 80 °C showed a higher percentage of NS In the treatment with H\textsubscript{2}O at 90 °C, there was no significant difference between the different levels of fruit maturation. Regarding the treatment with H\textsubscript{2}O at 100 °C, the seeds did not germinate; therefore, there was no formation of NS.

The FPF and FSR seeds showed a higher percentage of normal seedlings (66% and 58%, respectively) when not subjected to the treatments, that is, the control. In the case of FFF seeds, treatment with GA\textsubscript{3} (12%) and the control (16%) resulted in higher percentages of normal seedlings.
Table 4. Dry mass (DM) and normal seedlings (NS) of seedlings from seeds of *M. citrifolia* from freshly picked fruits (FFP), fruits stored in a refrigerator for seven days (FSR) and freshly fallen fruits (FFF), submitted to different pre-germination treatments.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>DM (mg)</th>
<th>NS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FPF</td>
<td>FSR</td>
</tr>
<tr>
<td>Control</td>
<td>3.90 cB</td>
<td>4.25 cB</td>
</tr>
<tr>
<td><strong>GA</strong>&lt;sub&gt;3&lt;/sub&gt;</td>
<td>4.25 bB</td>
<td>4.60 cB</td>
</tr>
<tr>
<td><strong>KNO&lt;sub&gt;3&lt;/sub&gt;</strong></td>
<td>4.72 bB</td>
<td>5.10 bB</td>
</tr>
<tr>
<td>H&lt;sub&gt;2&lt;/sub&gt;O 70 °C</td>
<td>4.38 bB</td>
<td>4.53 cB</td>
</tr>
<tr>
<td>H&lt;sub&gt;2&lt;/sub&gt;O 80 °C</td>
<td>7.00 aA</td>
<td>4.47 cC</td>
</tr>
<tr>
<td>H&lt;sub&gt;2&lt;/sub&gt;O 90 °C</td>
<td>0.00 dB</td>
<td>6.00 aA</td>
</tr>
<tr>
<td>H&lt;sub&gt;2&lt;/sub&gt;O 100 °C</td>
<td>0.00 dA</td>
<td>0.00 dA</td>
</tr>
<tr>
<td>CV (%)</td>
<td>9.2</td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same letter, lowercase in the column and uppercase in the row, do not differ from each other at a level of 5%, according to the Scott Knott test.

Source: Author

In relation to soluble solids, FFF presented higher levels (10.25) because they were more mature, causing greater accumulation of sugars (Table 5). However, the FSR presented lower contents (6.25), which is explained by storage in a refrigerator, and lower temperatures hinder the release of ethylene and thus delaying the ripening process.

Titratable acidity is a variable directly associated with the conservation of the quality of any food, and in the case of FFF, as they are already in a more advanced state of maturation, it could already be causing a loss of quality, justifying the value of acidity being higher than in the other fruit stages (0.71) (Table 5).

Table 5. Content of soluble solids and titratable acidity of freshly picked *M. citrifolia* fruits (FFP), fruits stored in a refrigerator for seven days (FSR) and freshly fallen fruits (FFF).

<table>
<thead>
<tr>
<th>Maturation stages</th>
<th>Soluble solids (<em>°Brix</em>)</th>
<th>Titratable acidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPF</td>
<td>8.50 b</td>
<td>0.23 b</td>
</tr>
<tr>
<td>FSR</td>
<td>6.25 c</td>
<td>0.23 b</td>
</tr>
<tr>
<td>FFF</td>
<td>10.25 a</td>
<td>0.71 a</td>
</tr>
<tr>
<td>CV (%)</td>
<td>10.20</td>
<td>7.88</td>
</tr>
</tbody>
</table>

Means followed by the same lowercase letter in the columns do not differ from each other at a level of 5%, by Tukey’s test.

Source: Author

The textural characteristics are parallel to the chemical characteristics of the fruits. Hardness is related to the force required to constrain a given food item. With ripening, the fruit becomes softer due to the rupture of the fibers, thus reducing the force necessary for compression, corroborating the results found for hardness, in which FFF presented a lower need for required force, that is, a lower hardness value (1.34 N) (Table 6).
Adhesiveness refers to the work done to overcome the attraction of food and the material that compresses it. In this case, the adhesion was higher in the FSR (0.55 mJ) (Table 6), as they were more resistant (with a higher hardness value of 20.40 N) because their degree of maturation was preserved by storage, making it more difficult to separate the fruit from the material used.

FFF presented higher values of cohesiveness (1.21), because, as they are softer, they withstand the compression force more before breaking, whereas the fruits that are firmer (FPF and FSR) tend to break more easily (Table 6).

Elasticity is the ability of a given food to return to its natural state even after being subjected to some modifications. The highest values were obtained by FPF (0.81 mm) and FSR (0.92 mm); because of their greater firmness, they are able to recover more easily. The softer fruit (FFF) tends to be crushed (Table 6), and Zsófi et al. (2014), in a study carried out with grapes, suggested that there is no direct relationship between the thickness of the skin and the firmness of the fruit, but it usually determines the elasticity.

Gumminess is related to the force required to disintegrate the food, that is, to dissociate its mass. The lowest value was obtained by the FFF (1.75 N) (Table 6), due to its softness, not requiring much force to fragment it, unlike the other stages of maturation, which require greater force due to greater firmness (Tunçel et al., 2014).

Table 6. Hardness, adhesiveness, cohesiveness, elasticity and gumminess characteristics of freshly picked M. citrifolia fruits (FPF), fruits stored in a refrigerator for seven days (FSR) and freshly fallen fruits (FFF).

<table>
<thead>
<tr>
<th>Maturation stages</th>
<th>Hardness (N)</th>
<th>Adhesiveness (mJ)</th>
<th>Cohesiveness</th>
<th>Elasticity (mm)</th>
<th>Gumminess (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPF</td>
<td>19.35 b</td>
<td>0.45 b</td>
<td>0.29 b</td>
<td>0.81 a</td>
<td>5.95 b</td>
</tr>
<tr>
<td>FSR</td>
<td>20.40 a</td>
<td>0.55 a</td>
<td>0.32 b</td>
<td>0.92 a</td>
<td>7.92 a</td>
</tr>
<tr>
<td>FFF</td>
<td>1.34 c</td>
<td>0.30 c</td>
<td>1.21 a</td>
<td>0.61 b</td>
<td>1.75 c</td>
</tr>
<tr>
<td>CV (%)</td>
<td>2.79</td>
<td>10.88</td>
<td>5.91</td>
<td>12.49</td>
<td>10.29</td>
</tr>
</tbody>
</table>

Means followed by the same lowercase letter in the columns do not differ from each other at a level of 5%, by Tukey's test.
Source: Author

Considering Pearson's correlation (Table 7) it can be seen that germination was not related to adhesiveness, presenting a non-significant value. However, when related to soluble solids, titratable acidity, and cohesiveness, a negative correlation was observed between the variables, being moderate for SS (-0.5848) and very strong for AT (-0.9531) and C (-0.9628), at a probability level of 1%; that is, when germination increases its value, the other variables decrease or vice versa. According to Pearson's correlation, relating germination to elasticity and
gumminess, moderate (0.6438) and strong (0.8072) positive correlations were observed between the variables at the 5% probability level. The interaction between germination and hardness showed a positive correlation; that is, as one increased, the other also increased, with the degree of this correlation being very strong (0.9428) at a level of 1% probability.

Table 7. Pearson correlation for noni fruit and seed characteristics. Soluble solids (SS), titratable acidity (AT), hardness (H), adhesiveness (A), cohesiveness (C), elasticity (E), gumminess (GU), germination (G), germination speed index (GSI), shoot length (SL), root length (RL), total dry mass (DM) and normal seedlings (NS).

<table>
<thead>
<tr>
<th>Variáveis</th>
<th>SS</th>
<th>AT</th>
<th>H</th>
<th>A</th>
<th>C</th>
<th>E</th>
<th>GU</th>
<th>G</th>
<th>GSI</th>
<th>SL</th>
<th>RL</th>
<th>DM</th>
<th>NS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS</td>
<td>-0.7728**</td>
<td>-0.7915**</td>
<td>-0.8958**</td>
<td>0.7221**</td>
<td>-0.896**</td>
<td>-0.9179**</td>
<td>-0.5848**</td>
<td>-0.5288**</td>
<td>0.4514**</td>
<td>0.7016**</td>
<td>0.3811**</td>
<td>-0.6922**</td>
<td></td>
</tr>
<tr>
<td>AT</td>
<td>-0.9923**</td>
<td>-0.8699**</td>
<td>0.9849**</td>
<td>-0.7823**</td>
<td>-0.9372**</td>
<td>-0.9531**</td>
<td>-0.9303**</td>
<td>0.8173**</td>
<td>0.5559**</td>
<td>0.8066**</td>
<td>-0.9758**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>0.8701**</td>
<td>-0.9925**</td>
<td>0.8030**</td>
<td>0.9523**</td>
<td>0.9428**</td>
<td>0.9192**</td>
<td>-0.8137**</td>
<td>-0.6001**</td>
<td>0.8059**</td>
<td>0.9764**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>-0.8271**</td>
<td>0.8030**</td>
<td>0.9324**</td>
<td>0.7249**</td>
<td>0.6714**</td>
<td>0.5582**</td>
<td>-0.7617**</td>
<td>-0.5350**</td>
<td>0.8136**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>-0.7418**</td>
<td>-0.9185**</td>
<td>-0.9628**</td>
<td>-0.9452**</td>
<td>0.8405**</td>
<td>0.5679**</td>
<td>0.8368**</td>
<td>0.8909**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>0.8817**</td>
<td>0.6438**</td>
<td>0.5699**</td>
<td>0.6049**</td>
<td>0.6787**</td>
<td>-0.6001**</td>
<td>0.8066**</td>
<td>0.9764**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GU</td>
<td>0.8072**</td>
<td>0.7703**</td>
<td>-0.6560**</td>
<td>-0.7249**</td>
<td>-0.6797**</td>
<td>0.8892**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>0.9940**</td>
<td>-0.9211**</td>
<td>-0.3614**</td>
<td>-0.8486**</td>
<td>0.9779**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GSI</td>
<td>-0.9211**</td>
<td>-0.3050**</td>
<td>-0.8552**</td>
<td>0.9604**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SL</td>
<td>0.2063**</td>
<td>0.7034**</td>
<td>-0.8919**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL</td>
<td>-0.2839**</td>
<td>-0.4800**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| DM        | -0.8559** | -

- not significant, ** - significant at 1% probability level and * - significant at 5% probability level by the F test.

Source: Author

4 DISCUSSION

Silva et al. (2012) studied *M. citrifolia* fruits produced in Mossoró-RN and observed that mature fruits had higher average lengths (101.08 mm) and widths (74.41 mm). However, in the present work, FSR were the ones that presented the highest average length in diameter.

According to Silva et al. (2017), fruit maturation stage influences the physiological quality of *M. citrifolia* seeds. Determining the fruit harvest stage is of great importance to avoid losses in the physiological quality of seeds which are due to immature seeds or seeds with compromised quality (DONATO et al., 2015).

According to Villa et al. (2016), gibberellic acid acts, above all, in the elongation of cells and in their division, which is directly related to their germination percentage and the growth and development of seedlings. Depending on the species, as well as the concentration of gibberellic acid, there may be a difference in behavior, acting as a stimulant or an inhibitor. Several studies have been conducted on the use of GA₃ in the germination of fruit seeds, and many differences have been observed.
In grenadilla seeds (*Passiflora ligularis* Juss), germination percentage increased when treated with GA$_3$ (CADORIN et al., 2017). The same was reported by Santos et al. (2013) for yellow passion fruit seeds (*Passiflora edulis* Sims. f. *flavicarpa* Deg.) GA$_3$ had a positive effect on seed germination. It promotes the expression of genes that control the synthesis of enzymes involved in the degradation of endosperm cell walls, leading to embryo growth and stimulating the germination process (CARVALHO et al., 2012; TAIZ et al., 2017).

The results for the seeds of freshly fallen fruits (FFF) were significantly higher, corroborating the findings of Cadorin et al. (2017) when the seeds were treated with GA$_3$. However, the germination speed increased as a function of gibberellic acid concentration.

According to Pereira et al. (2021), seed treatment with GA$_3$ results in maximum relative growth and net assimilation rates, accelerating seedling growth and development.

Pre-germination treatment in heated water can also yield satisfactory results. However, Riet et al. (2017), working with *Bauhinia variegata* Linn, found that immersion in water at 80 °C caused death of all seeds, showing a species-dependent factor. On the other hand, the treatment performed by Souza et al. (2019) consisting of immersion in hot water at 100 °C resulted in better germination performance, suggesting that it is more suitable for the production of *Apeiba tibourbou* seedlings.

GA$_3$ also exerted positive effects on root growth. However, according to Vendruscolo et al. (2016), the action of GA$_3$, which results in cell elongation, can promote the growth of the aerial part of the plant and inhibit the formation of new roots, which consequently results in a disproportionality in plant growth and a lower mass of the plant root dry matter.

Among the different dormancy-breaking methods, KNO$_3$ is widely used (BRASIL, 2009). Nunes et al. (2015) found that the substrate, when moistened in a KNO$_3$ solution, did not change the dry mass of seedlings, and the imbibition of seeds in the solution, together with the removal of the pericarp, did not influence the dry mass, although it promoted growth of the aerial part. According to Kaiser et al. (2016), when salinity is present, KNO$_3$ at different concentrations can give positive results, as is the case with the concentration of 0.01 mmol L$^{-1}$, whose average dry mass was higher than the control.

However, fruits harvested early may have seeds with low physiological quality, as there is an interruption in the fruit maturation process, which negatively influences seed quality (RUBIO et al., 2013).
In contrast to the data found, Pereira et al. (2016) observed that the results were similar both in the industrial seed treatment and in treatments with the use of a bioregulator (mixture of kinetin, 4-indol-3-ylbutyric acid, and gibberellic acid), noting that the mixture did not have a positive effect on the percentage of normal seedlings. According to Santos et al. (2013), considering the length of normal roots and seedlings, the results of the analysis of variance did not show significant differences in relation to the characteristics that were analyzed.

These results corroborate those found by Silva et al. (2012) in *M. citrifolia* fruits, in which the soluble solid content was higher when the maturation stage was more advanced, which is the result of starch degradation. However, Menezes et al. (2017) did not find differences in the soluble solid content of *Spondias tuberosa* fruits at different stages of maturation.

Due to the increase in the degree of maturation, there is an increase in the content of soluble solids due to the dissolution of sugars, together with other substances, resulting in an increase in sweetness in the fruits (PERFEITO et al., 2015). In the present study, the values obtained in FPF and mature in the mother plant were 8.50 °Brix and 10.25 °Brix in the FFF.

Similar results were found by Canuto et al. (2010) and Correia (2011), in *M. citrifolia* fruits, with values of 0.32 and 0.62 g 100 g\(^{-1}\) of pulp, respectively. Perfect et al. (2015), in a study carried out with *Hancornia speciosa* fruits, found that acidity resulted in green fruits being higher than ripe or semi-ripe fruits, in contrast to the results found in this study.

Silva et al. (2012) obtained similar results in a study carried out with *M. citrifolia* fruits, in which they observed greater hardness in fruits with a lower degree of maturation and, according to the increase in maturation, this hardness was reduced. The same was observed by Perfect et al. (2015), who observed a considerable decrease in the force necessary for perforation of *Hancornia speciosa* fruits when maturation was at a higher degree.

However, with an increase in the degree of maturation, the adhesiveness was reduced, which was attributed to the rupture of the pectin networks, reducing the adhesiveness and, consequently, the firmness (DIAS et al., 2011). Cohesiveness is how much a food can withstand being compressed before it breaks, that is, how much it can withstand being deformed before breaking (ZUO et al., 2016).

Based on this result, by analyzing the characteristics of the fruit, it is possible to choose the ideal degree of maturation to obtain seeds with high physiological quality, thus guaranteeing a more uniform and vigorous stand, as the Pearson correlation is used to measure the relationship...
between two variables and, if it exists, whether it is positive or negative, and the degree of relationship between them. The values of this relationship must be between -1 and 1, and values closer to 1, whether negative or positive, mean a very strong or strong correlation, median values mean a moderate correlation, and values further from 1 indicate a weak correlation, which can be negligible. Positive values indicate that the relationship between the variables is positive; that is, when one increases, the other also increases, or when one decreases, the other decreases. Negative values suggest that the relationship is negative, that is, if one variable increases, the other decreases, or vice versa (FIGUEIREDO FILHO et al., 2014).

5 CONCLUSIONS

*M. citrifolia* seeds do not show tegumentary dormancy.

The seeds of freshly harvested fruits and fruits harvested after seven days of maturation did not require pre-germination treatments.

Gibberellic acid promotes greater germination in seeds of fruits harvested from the ground.

Fruits that have fallen to the ground have a higher content of soluble solids and higher acidity.

The storage of fruits in a refrigerator for a week maintains textural characteristics, such as hardness, adhesiveness, elasticity, and gumminess.

Fruits with greater hardness have higher physiological seed quality.

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