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ANÁLISE DE QUALIDADE DA ÁGUA DE COCO *IN NATURA* E SUAS CARACTERÍSTICAS FÍSICO-QUÍMICAS EM SANTA IZABEL DO PARÁ

ERMANO PRÉVOIR[1]; JOAQUIM ALVES DE LIMA JUNIOR[2]; ITALO MARLONE GOMES SAMPAIO[3]; MARIA DO BOM CONSELHO LACERDA MEDEIROS[4]; PAULO MANOEL PONTES LINS[5] E MARCOS AUGUSTO DE SOUZA GONÇALVES[6]

[1]Departamento de Pós-graduação em Agronomia, Universidade Federal Rural da Amazônia (UFRA), Avenida Barão de Capanema, S/Nº, no bairro Caixa D'água, 68700-665, Capanema, Pará, Brasil. E-mail: permano89@gmail.com ORCID: https://orcid.org/0000-0002-7845-5967

[2] Departamento de Pós-graduação em Agronomia, Universidade Federal Rural da Amazônia (UFRA), Avenida Barão de Capanema, S/Nº, no bairro Caixa D'água, 68700-665, Capanema, Pará, Brasil. E-mail: joaquim.junior@ufra.edu.br ORCID: https://orcid.org/0000-0001-9003-7998

[3] Departamento de Ciências Agrárias, Instituto Federal do Amapá, Campus Agrícola, Br 210 Km 103, Rn, Retiro dos Pinhais, 68.997-000, Porto Grande, Amapá, Brasil. Email: italo.sampaio@ifap.edu.br ORCID: https://orcid.org/0000-0002-0801-6408

[4] Departamento de Pós-graduação em Agronomia, Universidade Federal Rural da Amazônia (UFRA), Avenida Presidente Tancredo Neves, 2501, terra firme, 66077-830, Belém, Pará, Brasil. E-mail: melmedeirosagro@gmail.com ORCID: https://orcid.org/0000-0002-1364-6877

[5] Departamento de Pós-graduação em Agronomia, Universidade Federal Rural da Amazônia (UFRA), Avenida Presidente Tancredo Neves, 2501, terra firme, 66077-830, Belém, Pará, Brasil. E-mail: paulom@sococo.com.br ORCID: https://orcid.org/0000-0002-0012-3460

[6]Departamento de Pós-graduação em Agronomia, Universidade Federal Rural da Amazônia (UFRA), Avenida Presidente Tancredo Neves, 2501, terra firme, 66077-830, Belém, Pará, Brasil. Email: augustosouza717@gmail.com ORCID: https://orcid.org/0000-0002-5507-5515

1 RESUMO

Este estudo teve como objetivo analisar a qualidade físico-química da água de coco in natura produzida em Santa Izabel do Pará (PA), sob diferentes estratégias de manejo hídrico-nutricional. O experimento foi conduzido em esquema fatorial 4×3, com tensões de água no solo (15, 30, 45 e 60 kPa) e fertirrigação (100, 200 e 300% da recomendação de NPK+Mg), com três repetições. Determinaram-se pH, Sólidos Solúveis Totais (SST, °Brix) e condutividade elétrica (CE). A ANOVA indicou interação significativa entre fertirrigação e tensão de água no solo ($p > 0,005$). A amplitude das variações foi pequena, sem comprometimento da qualidade global da água de coco. O pH variou de 5,22 a 5,59, mantendo-se dentro do intervalo estabelecido pela legislação brasileira (IN MAPA nº 9/2020). Os SST variaram de 6,35 a 7,04 °Brix, com valores superiores ao mínimo regulatório. A CE variou de 5,95 a 7,11 mS cm^{-1}. Conclui-se que doses elevadas de fertirrigação não implicam melhoria proporcional dos atributos físico-químicos.

Palavras-chave: *Cocos nucifera* L., condutividade elétrica, pH, fertirrigação, tensão de água no solo.

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QUALITY ASSESSMENT OF FRESH COCONUT WATER AND ITS PHYSICOCHEMICAL CHARACTERISTICS IN SANTA IZABEL, PARÁ, BRAZIL

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2 ABSTRACT

This study aimed to analyze the physicochemical quality of fresh coconut water produced in Santa Izabel do Pará, Brazil, under different water–nutrient management strategies. The experiment followed a 4×3 factorial design combining water tension levels (15, 30, 45, and 60 kPa) and fertigation rates (100, 200, and 300% of the recommended NPK+Mg), with three replications. The pH, total soluble solids (TSS), and electrical conductivity (EC) were measured. ANOVA revealed a significant interaction between fertigation and soil water tension ($p > 0.005$). The variation magnitude was limited and did not compromise overall product quality. The pH ranged from 5.22 to 5.59. The TSS ranged from 6.35 to 7.04 °Brix. The EC varied from 5.95 to 7.11 mS cm^{-1}.

Keywords: *Cocos nucifera* L., electrical conductivity, pH, fertigation, soil water tension.

3 INTRODUCTION

The coconut palm (*Cocos nucifera* L.) is a perennial crop of high economic importance in tropical regions. Its agronomic value stems from the diversity of products obtained from the fruit, including oil, copra, fibers, and especially coconut water (Medina et al., 2005; Costa et al., 2006). Coconut water corresponds to the liquid endosperm accumulated in young fruits. Consumption has grown in both its *natural* and processed forms. This expansion is driven by its nutritional and sensory profile. It is a low-calorie beverage that is rich in electrolytes such as potassium, sodium, calcium, and magnesium and has high organoleptic acceptance by consumers (Costa et al., 2005; Brazil, 2020).

Among the varietal groups, dwarf varieties, especially the green dwarf coconut palm, play a central role in commercial exploitation of coconut water. This prominence results from favorable agronomic characteristics. The crop exhibits early production, regular flowering, a relatively high volume of water per fruit, and a thin solid endosperm. These characteristics are associated with better sensory acceptance and greater product competitiveness in the market (Passos, Passos and Aragão, 2007). Moreover, consumption has expanded in large urban centers. Commercialization occurs through both the consumption of bottled beverages and the direct sale *of fresh coconut*. This scenario has enhanced the production chain and encouraged producers to adopt more efficient management strategies, focusing on quality and competitiveness (Miranda et al., 2018).

In Brazil, approximately 220,700 hectares of coconut is cultivated. The highest concentration is in the northeast, which is responsible for approximately 87% of national production (FAO, 2019). However, the North region has been expanding its share. The state of Pará has consolidated itself as an emerging center and accounts for approximately 12.2% of the country's production (IBGE, 2019). This expansion is favored by the edaphoclimatic conditions of northeastern Pará. A humid tropical climate predominates, with high availability of radiation and sandy soils. These factors allow for year-round production when associated with adequate water and nutrient management (Cintra et al., 2009; Miranda et al., 2018).

On the other hand, these same conditions represent a technical challenge. High rainfall, combined with the sandy texture of the soil, intensifies nutrient leaching. This requires greater precision in terms of fertilization management, especially for nitrogen, phosphorus,

potassium, and magnesium. These nutrients are essential for plant growth, photosynthesis, assimilate transport, osmotic regulation, and the formation of fruit yield and quality (Faquin, 2005; Câmara, 2016; Aviz, 2021).

In this context, irrigation and fertigation practices become strategic for green dwarf coconut palm. Crops present continuous production and demand a water–nutritional balance throughout the production cycle (Miranda et al., 2018). Evidence indicates that water and nutritional management influence the physicochemical attributes of coconut water. Among these, total soluble solids (°Brix), pH, total titratable acidity, and electrical conductivity stand out. These parameters are directly associated with the sensory acceptance, stability, and market value of the product (Aragão et al., 2001; Silva et al., 2013; Barbosa et al., 2021; Araújo et al., 2022).

Moderate water deficit can alter the relationship between solute concentration and water volume in the fruit. Excess water, in turn, can promote dilution and affect sensory perception. Furthermore, the poor synchronization of fertilization with water availability reduces the efficiency of nutrient absorption and redistribution. This imbalance affects the composition of the liquid endosperm (Ferreira Neto, 2005; Araújo et al., 2022). Despite the importance of this topic, regional studies that systematically characterize the physicochemical quality of *fresh coconut water* in northeastern Pará are still scarce, especially in scenarios of intensified management.

Given this context, the present study aimed to analyze the quality of *fresh coconut water* on the basis of the physicochemical characteristics of fruits produced in the municipality of Santa Izabel do Pará. The goal is to generate regional technical information to support management practices and contribute to the strengthening and sustainability of the coconut production chain.

4 MATERIALS AND METHODS

The experiment was conducted at Fazenda Reunidas Sococo, in the municipality of Santa Izabel do Pará, state of Pará, Brazil (01°13'40.16" S; 48°02'54.35" W). The study was carried out in a commercial coconut (*Cocos nucifera* L.) plantation, cultivar Anã Verde do Brasil, which is eight years old. The planting was established at a spacing of 7.5 m in an equilateral triangle, occupying a total area of 1.34 ha. The experimental period ranged from June 2022 to March 2023.

The region's climate is classified as AFi (humid tropical) according to Köppen. The area has high annual rainfall, with an average precipitation between 2,500 and 3,000 mm. During the experimental period, an average temperature of 27°C and an average relative humidity of 78% were recorded. The thermal amplitude is low, which is characteristic of northeastern Pará. The terrain is flat to gently undulating, favoring uniform water and nutrient management. The soil was classified as Quartzarenic Neosol, with a sandy texture and yellowish coloration throughout the profile, according to the Embrapa classification (2008).

The experiment was conducted in a randomized complete block design (RCBD) in a 4 × 3 factorial scheme with three replications. Twelve treatments were evaluated, totaling 36 experimental units. The use of the RCBD aimed to control the spatial variability of the area associated with natural soil and moisture gradients, even under uniform agricultural management.

The blocking variable was the position of the plots within the experimental area. The orientation of the area and the relative edaphic homogeneity within each block were considered. The blocks were

structured as parallel strips, each containing all treatment combinations. This arrangement ensured greater internal homogeneity and reduced experimental error.

Treatment randomization was performed independently in each block by random selection using R software (RStudio). Each combination of levels occurred only once per block. The list of randomized treatments defined the arrangement of the plots in the field. The physical contiguity of the experimental units and the permanent identification of the plants were respected. These procedures minimized border effects and ensured traceability throughout the experiment. Randomization was recorded and archived for later verification and reproducibility of the design.

The first experimental factor corresponded to four levels of water management, defined by soil water tensions of 15, 30, 45, and 60 kPa. Monitoring was carried out using sensors installed in the root zone. The second factor corresponded to three fertilization levels: 100%, 200%, and 300% of the recommended NPK+Mg. The application was carried out via fertigation (Table 1).

Each experimental unit consisted of 18 plants arranged in double rows. The six central plants constituted the useful plot. The remaining plants were used as borders to reduce edge effects.

Irrigation was carried out using a microsprinkler system, with one emitter per plant. Fertigation was applied for six months throughout the year, according to the treatments. Nutritional management was adjusted on the basis of the results of the foliar analyses, with the goal of meeting the crop requirements at each fertilization level.

The nutrient doses applied via fertigation are presented in Table 1. The values are expressed in kg ha^{-1} and were calculated on the basis of technical recommendations for coconut cultivation, considering sources of N, P_2O_5, K_2O and Mg (Lins & Viegas, 2008).

Table 1. Nutrient doses applied via fertigation to g plants $^{-1}$ year $^{-1}$

Fertigation	Nutrients			
	N	K2O	P_2O_5	Mg
100%	657.22	745.5	371.94	830.55
200%	1,314.44	1,491	743.88	1,661.1
300%	1,971.66	2,236.5	1,115.82	2,491.65

Source: Authors (2026).

Fruit collection was performed using simple random sampling. The plants within the useful plot were selected by manual drawing. Nine fruits were collected per experimental unit every 21 days. Harvesting occurred in bunches approximately seven months after inflorescence opening. The procedure was carried out between 6:00 and 8:00 in the morning, a period of less temperature variation.

After being harvested, the fruits were transported to the company's in-house laboratory. The natural state of the coconut water was extracted using a previously sanitized stainless steel knife. The liquid was filtered and stored in 100 mL laboratory-grade polyethylene bottles. The bottles were previously washed, sanitized, and dried and hermetically sealed to prevent cross-contamination.

The samples were stored in a freezer at -18°C. This temperature is considered adequate for preserving the physicochemical characteristics without significantly interfering with the analyzed parameters. The samples were subsequently packed in a thermal box with ice packs. The internal temperature was maintained below 10°C

during transport to the CTA Laboratory – Center for Agricultural Technology of the Federal Rural University of the Amazon (UFRA). The transport took approximately 50 minutes.

Physicochemical analyses were performed according to the methods of the Adolfo Lutz Institute (2008). The determination of total soluble solids (°Brix) was carried out using an INTRUTHERM® analytical refractometer (model RT-90 ATC). The equipment has automatic temperature compensation and was calibrated with distilled water before the measurements. °Brix was adopted as an indicator of solute concentration, according to Normative Instruction No. 9/2020.

The electrical conductivity (EC) of a 10 mL sample that had been previously homogenized was determined. An LUTRON® conductivity meter (model CD-4301), calibrated with standard solutions, was used. Readings were taken after signal stabilization, with automatic temperature compensation. The results are expressed in mS cm^{-1}.

The hydrogen ion potential (pH) was determined using the potentiometric method. A LUCADEMA® pH meter (model mPA210), calibrated with buffer solutions with a pH of 4.0, 7.0, and 10.0, was used, according to Method 017/IV of the Adolfo Lutz Institute (2008). Measurements were performed with temperature control. All analyses were conducted in triplicate, with three readings per sample. The outliers were checked, and when necessary, the analyses were repeated to ensure data reliability.

The data were subjected to analysis of variance (ANOVA), considering the adopted experimental design. The assumptions of normality of residuals and homogeneity of variances were previously verified. When significant differences were detected, the means were compared using Tukey's test at a 5% probability level ($p \leq 0.05$).

Statistical analyses were performed using RStudio software. Complementary parameters were calculated, including the standard error of the means and the coefficient of variation (CV), to assess experimental precision.

5 RESULTS AND DISCUSSION

The results obtained reflect the combined effect of water and nutritional management on the physicochemical parameters of coconut water. Analysis of variance (ANOVA) indicated a significant interaction between fertigation (F) and soil water tension (T) for all the variables evaluated (pH, °Brix, and electrical conductivity). These results confirm that the response of the physicochemical parameters depends on the combination of factors. The average data are shown in Tables 2 and 3 and in Figures 1 to 3.

Table 2. Summary of the analysis of variance for hydrogen ion potential (pH), total soluble solids (TSS) and electrical conductivity (EC) as a function of fertigation level and soil water tension.

Variation factor	GL	Test F		
		pH	CE	SST
			mS.cm $^{-1}$	°Brix
Blocks	2	0.21ns	0.40ns	0.63ns
Fertigation (F)	2	103.32***	16.35***	12.75***
Voltages (T)	3	239.85***	47.25***	11.67***
F x T	6	343.26***	25.60***	21.52***
Waste	22	-	-	-
Total	35			
CV%		0.19%	1.68%	1.05%

***= p< 0.001. ns: not significant
Source: Authors (2026).

The pH of the coconut water ranged from 5.32 to 5.59 (Table 3; Figure 1). This range is consistent with reported values for fresh coconut water and characterizes a low-acidity beverage. Tukey's test (5%) revealed differences within each water tension.

Under 15 kPa, a complete gradient occurred between doses (100% > 200% > 300%). The highest value was observed at 100% × 15 kPa (5.593 ± 0.01). The lowest occurred at 300% × 15 kPa (5.323 ± 0.003). At 30 kPa, the hierarchy was altered. The lowest pH of the experiment occurred at 200% × 30 kPa (5.220 ± 0.006). These values were lower than those of the other fertilization levels.

At 45 kPa, the maximum pH was recorded at 300% × 45 kPa (5.547 ± 0.007). This treatment differed from the others. The lowest value at this tension occurred at 100% × 45 kPa (5.327 ± 0.007). At 60 kPa, there was no difference between doses. All averages are indicated by the same lowercase letter (Table 3). This pattern suggests that the pH is stabilized under greater water restriction.

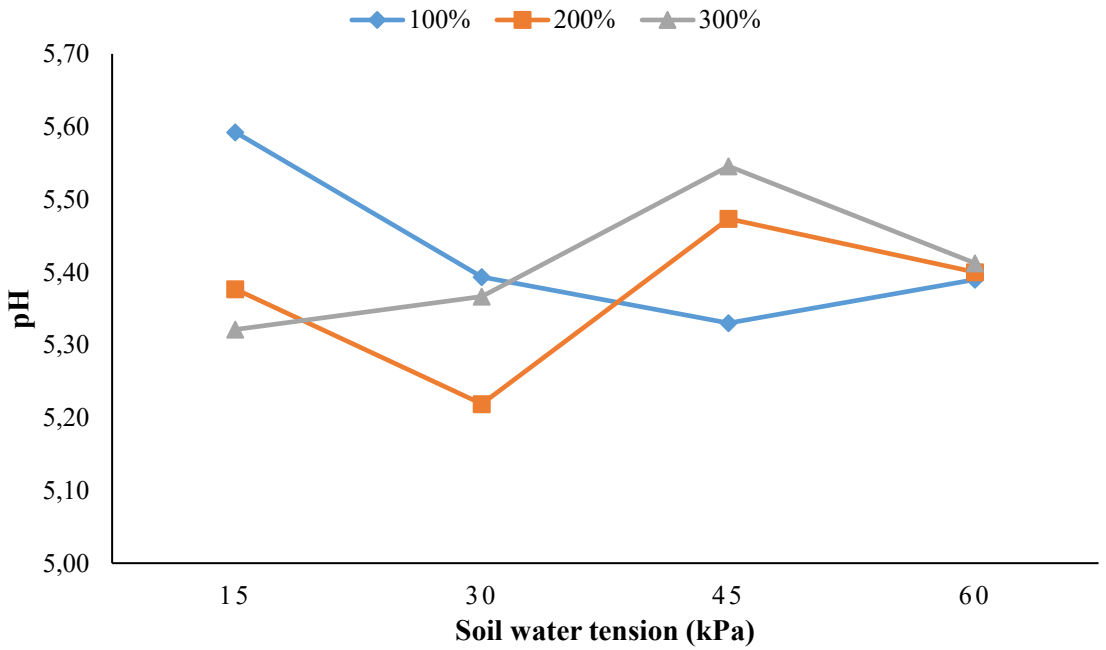
Table 3. pH, total soluble solids (TSS) and electrical conductivity (EC) of fresh coconut water (mean ± standard error, SE) as a function of the interaction between fertigation level (F) and soil water tension (T).

Fertigation/ Tension	15 kPa	30 kPa	45 kPa	60 kPa
		pH		
100% NPK+Mg	5.593 ± 0.01 aA	5.397 ± 0.009 aB	5.327 ± 0.007 cC	5.390 ± 0.010 aB
200% NPK+Mg	5.377 ± 0.003 bC	5,220 ± 0.006 cD	5.473 ± 0.003 bA	5,400 ± 0,006 aB
300% NPK+Mg	5.323 ± 0.003 cD	5.367 ± 0.003 bC	5.547 ± 0.007 aA	5.413 ± 0.007 aB
		SST		
100% NPK+Mg	6.57 ± 0.03 aB	6.70 ± 0.00 aB	6.53 ± 0.03 bB	7.04 ± 0.07 aA
200% NPK+Mg	6.60 ± 0.00 aB	6.35 ± 0.03 bC	6.77 ± 0.03 aA	6.67 ± 0.03 bA
300% NPK+Mg	6.70 ± 0.06 aA	6.80 ± 0.06 aA	6.80 ± 0.00 aA	6.63 ± 0.03 bA
		CE		
100% NPK+Mg	6,820 ± 0,025 aA	6.277 ± 0.064 bB	6.027 ± 0.038 bB	6.907 ± 0.104 aA
200% NPK+Mg	6.603 ± 0.007 bA	6.733 ± 0.048 aA	6.307 ± 0.058 aB	6.813 ± 0.079 aA
300% NPK+Mg	6.020 ± 0.036 cB	6,030 ± 0,032 cB	6.557 ± 0.099 aA	6.833 ± 0.083 aA

Source: Authors (2026).

The observed behavior confirms the absence of a monotonic trend with increasing dose or voltage. The pH response depends on the water regime. This pattern explains the observed F × T interaction (Figure 1).

Figure 1. pH as a function of the fertigation level (100, 200 and 300%) and soil water tension (15, 30, 45 and 60 kPa)



Source: Authors (2026).

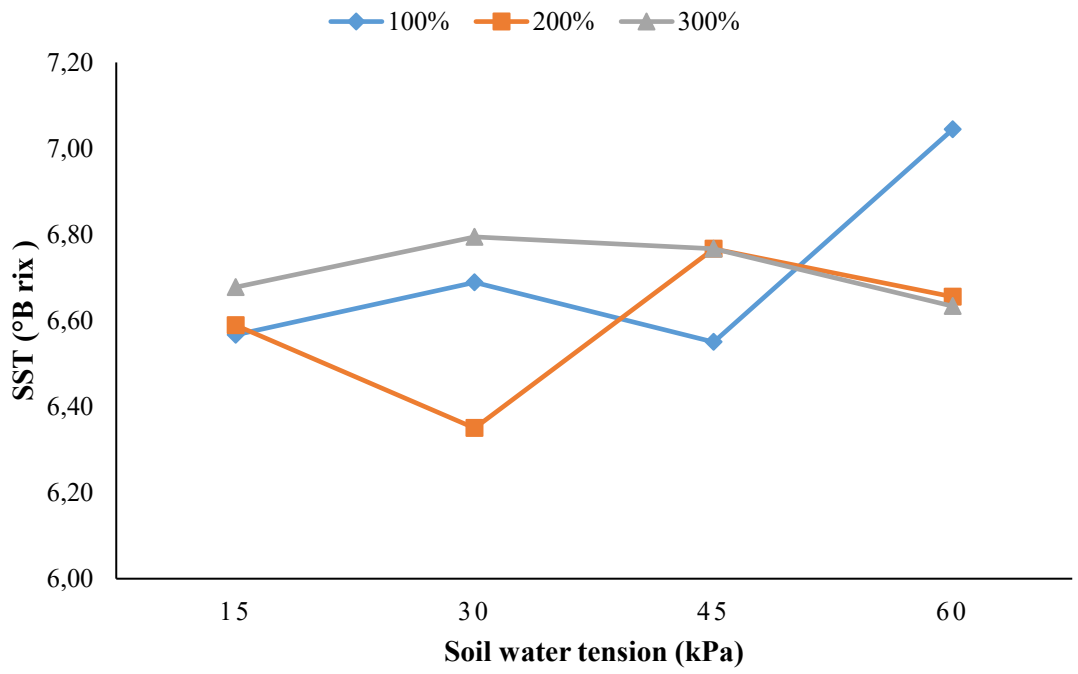
All the measured values met the Brazilian standard for processed coconut water. Legislation is used to establish a pH range between 4.0 and 6.5 (Brazil, 2020). Therefore, no combination of management practices compromised product compliance.

pH is a key indicator of sensory and microbiological quality. Values close to 5.5 are considered ideal, as they balance sweetness and acidity. They also reduce the risk of microbiological deterioration. The results obtained agree with those of studies carried out in different regions of Brazil, which reported pH values between 4.8 and 5.9 (Vasconcelos et al., 2015; Lima et al., 2015; Mendonça et al., 2020).

The observed stability suggests a low sensitivity of pH to moderate variations in fertigation and water management. The control of this parameter appears to be strongly associated with the physiological stage of the fruit. This behavior was previously described by Aragão et al. (2001) and Imaizumi et al. (2016).

In addition to acidity, the quality of coconut water is directly associated with the total soluble solids content, which reflects the content of dissolved sugars and solutes. The total soluble solids (TSS, °Brix) values ranged from 6.35 to 7.04 (Table 3; Figure 2). The highest value was recorded in the 100% NPK+Mg treatment at 60 kPa (7.04 ± 0.07 °Brix). The lowest occurred at 200% at 30 kPa (6.35 ± 0.03 °Brix).

Figure 2. Total soluble solids (°Brix) as a function of the fertigation level (100, 200 and 300%) and soil water tension (15, 30, 45 and 60 kPa).



Source: Authors (2026).

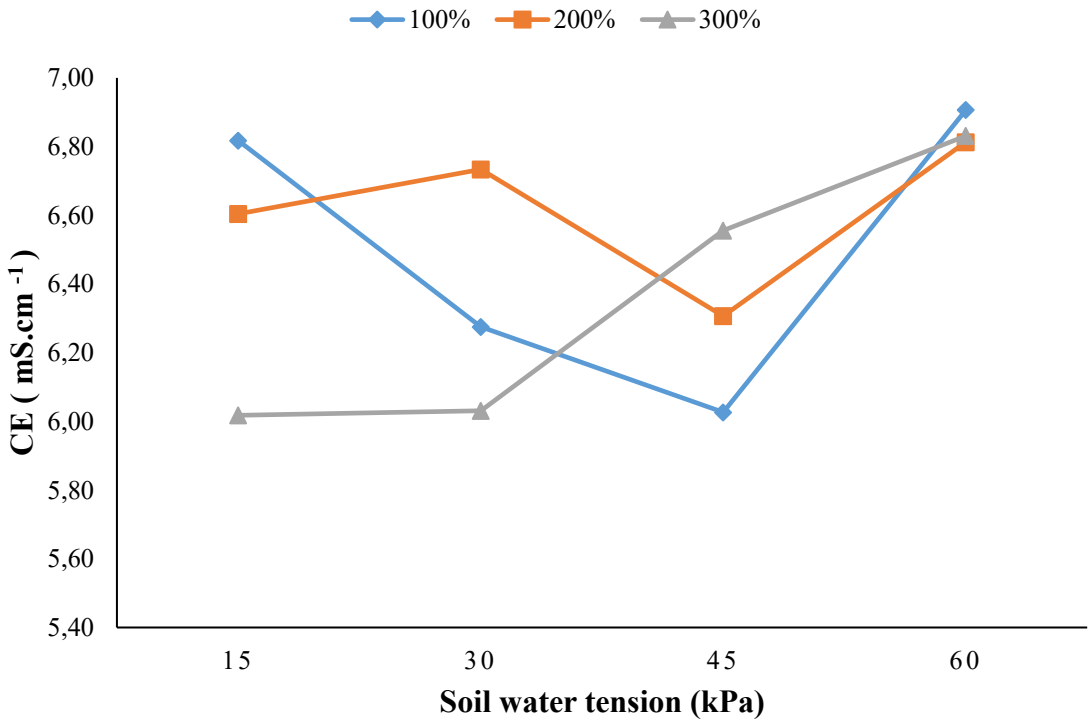
Tukey's test (5%) confirmed the absence of a single response pattern. At 15 kPa, there was no difference between doses. At 30 kPa, the 200% dose resulted in a lower TSS than 100% and 300%. At 45 kPa, the 200% and 300% doses exceeded 100%. At 60 kPa, the opposite occurred, with 100% exceeding the other doses. This behavior indicates that the TSS is modulated by specific combinations of water and nutritional management. The response does

not depend exclusively on increased fertilization (Figure 2).

All total soluble solids (TSS) values observed in this study were higher than the minimum limit of 4.0 °Brix established by MAPA Normative Instruction No. 9/2020 for coconut water, indicating a product with adequate sweetness for consumption. TSS is directly related to sensory perception, as it predominantly represents the concentration of dissolved sugars; thus, the averages obtained (6.6–6.8 °Brix) indicate a desirable sensory profile. This interpretation is corroborated by Silva et al. (2013), who highlight the relationship between TSS and the sensory quality of coconut water. Similarly, Martins et al. (2018) reported that fruits intended for consumption, aged between six and seven months, generally present values close to 6 °Brix because of the predominance of glucose, fructose, and sucrose, whereas Aroucha et al. (2014) reported that dwarf cultivars accumulate reducing amounts of sugars even in green fruits, resulting in a naturally sweet taste. From a physiological point of view, the results reflect the balance between solute accumulation and dilution by the volume of water in the fruit, since water management can influence °Brix through a dilution effect, as described by Azevedo et al. (2006). However, in the present study, this response was not uniform among the treatments, indicating that the TSS concentration depends on the interaction between water availability and fertilization, as evidenced by the significant interaction between the factors evaluated.

Another relevant parameter for characterizing quality is electrical conductivity, which expresses the total concentration of dissolved electrolytes. Electrical conductivity (EC), as well as pH and TSS, significantly differed between fertigation (F) and soil water tension (T) (Table 2; Figure 3).

Figure 3. Electrical conductivity (mS.cm $^{-1}$) as a function of the fertigation level (100, 200 and 300%) and soil water tension (15, 30, 45 and 60 kPa).



Source: Authors (2026).

The electrical conductivity (EC) ranged from 5.95 to 7.11 mS cm^{-1}, with averages between 6.02 and 6.91 mS cm^{-1} (Table 3). Analysis of the interaction between fertigation and soil water tension indicated no linear response to the evaluated factors, highlighting the dependence on the combination of water and nutritional management. The highest value was observed at 100% × 60 kPa (6.91 ± 0.10 mS cm^{-1}), whereas the lowest occurred at 300% × 15 kPa (6.02 ± 0.04 mS cm^{-1}). According to Tukey's test (5%), at 15 kPa, the EC decreased with increasing fertilization dose (100% > 200% > 300%), whereas at 30 kPa, the 200% dose resulted in the highest values. At 45 kPa, the 300% dose resulted in higher EC than the other treatments did, whereas at 60 kPa, no significant differences were observed between the fertilization levels. These results confirm that the EC response should be interpreted on the basis of the unfolding of the F × T interaction, since the effects of fertigation vary depending on soil water availability (Figure 3).

From a physiological point of view, electrical conductivity (EC) is the total concentration of dissolved electrolytes in the liquid endosperm and reflects the balance between solute accumulation and dilution by the water volume of the fruit. Under conditions of higher water availability (15 kPa), increased water flow can favor the relative dilution of ions, resulting in lower EC values under certain management combinations. On the other hand, under moderate to high tension (30–60 kPa), the increase in EC may be associated with a higher concentration of solutes resulting from osmotic adjustment mechanisms, by which plants accumulate osmotically active compounds to maintain cell turgor under water-restricted conditions, as described by Taiz et al. (2017). The observed values were consistent with those reported by Ferreira et al. (2007), indicating a balanced mineral composition of coconut water and no evidence of excessive salinization. Furthermore, the absence of a consistent trend between the EC and fertigation levels suggests that the ionic composition of coconut water is predominantly regulated by the physiological mechanisms of the plant and is influenced by the stage of fruit maturation and by the season, as reported by Câmara et al. (2021) and Kannangara et al. (2018).

Although the interaction between F and T was statistically significant, no treatment was consistently superior in terms of physicochemical quality. All combinations maintained the pH, TSS, and EC within ranges suitable for consumption. The results indicate high quality stability under different water and nutritional scenarios.

6 CONCLUSIONS

The *fresh* coconut water produced in this research in Santa Izabel do Pará presented adequate physicochemical quality for consumption. The pH (5.22–5.59), total soluble solids (6.33–7.03 °Brix) and electrical conductivity values remained within ranges compatible with sensory and technological standards, meeting the applicable normative criteria.

The interaction between fertigation and soil water tension was significantly different. However, the magnitude of the variations was small and did not compromise the overall quality of the product. No specific management combination stood out as superior in terms of physicochemical quality.

The results indicate the stability of coconut water across the entire experimental range (15–60 kPa; 100–300% NPK+Mg). This range demonstrates a safe management margin for commercial production in the studied region.

High doses of fertigation do not result in a proportional improvement in quality. Balanced water and nutrient

management strategies can be adopted without compromising the final product. This approach promotes the productive efficiency and sustainability of the coconut supply chain.

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