The use of *Moringa oleifera* Seeds in the Treatment Water from the Negro River for Indigenous Communities in the State of Amazonas, Brazil

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***Abstract*— *The poor quality of water intended for human consumption is one of the problems that has led to the appearance of several human diseases. The seeds of Moringa oleifera Lam. Can be used as a sustainable and low-cost alternative for water treatment. The aim of this study was to develop alternative methods of treating water for human consumption through the use of Moringa oleifera seeds. Water samples were collected at four points along the Negro River, in the state of Amazonas, for treatment with moringa seeds and simplified filtration systems. The samples were subjected to five types of treatment and compared to untreated samples and drinking water parameters, established by the Ministry of Health. Significant differences were observed in the following physical and chemical parameters of treated and untreated water: color, turbidity, dissolved solids total hardness, total alkalinity, electrical conductivity and ammonia content. The results suggest the possibility that moringa seeds can be used to produce better quality water for human consumption, especially in the case of people living in indigenous communities far from urban areas and without access to any type of water treatment.*

***Keywords*— Alternative, Moringa oleifera Seeds, Natural Coagulant, Water Treatment.**

I. INTRODUCTION

The poor quality of water intended for human consumption is one of the problems that has led to the emergence of numerous human diseases, whether it be the quality of water used to process and prepare food, water for personal hygiene or water for drinking. Limited access to drinking water and a shortage of clean water constitute a major challenge facing developing countries(1). According to a recent United Nations (UN) report, 2.1 billion people do not have drinking water in their homes(2). The World Health Organization (WHO) estimates that almost 159 million people depend on surface water and at least 2 billion people use drinking water contaminated with feces(3).

The Negro River in the Brazilian Amazon is one of the largest rivers in the world and the main left-bank tributary of the Solimões River, also in the Amazon. Considered the largest and best example of a blackwater river, the Negro River is the most chemically different river of all Brazilian rivers(4). It contains very small quantities of minerals and is rich in organic material, which gives it its dark, typically brown, color(5).

The Negro River drains five municipalities in the state of Amazonas: São Gabriel da Cachoeira, Santa Isabel do Rio Negro, Barcelos, Novo Airão and Manaus. This study was carried out in the municipality of São Gabriel da Cachoeira, which is notable for its predominantly indigenous population, who survive essentially on subsistence farming and hunting. Among the various

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health problems faced by the population, the most significant are inadequate water treatment and limited access to basic sanitation. Residents of the town of São Gabriel da Cachoeira drink water from artesian wells or directly from the Negro River and only have access to sodium hypochlorite in local health centers. Other inhabitants who live farther away in rural areas of the municipality along different tributaries of the Negro River (Uaupés and Içana, among others) get all their water from the river.

As the water consumed by people living in isolated, rural, indigenous communities and without access to facilities is not treated, diseases are common in this population. A viable solution to this problem would therefore be to develop a means of treating the water of the Negro River for these indigenous communities. An innovative, simple and sustainable solution would be to use the seeds of *Moringa oleifera* Lam. to purify the water in this river.

Moringa oleifera is a tropical tree native to Asia that is cultivated in Africa and Central and South America. It is one of thirteen species in the family Moringaceae (order Brassicales)(6). The tree is tolerant of drought and can blossom and produce fruit under these conditions(7). The species has been known in the state of Maranhão since 1950(8). Flocculation of impurities in water is a typical use of crushed moringa seeds and has been the subject of scientific investigation for almost 40 years(9). The seeds of the moringa tree contain soluble protein which acts as a clarifier and destabilizes particles in water(10,11). They are used in the treatment of raw water and effluent to remove the color and turbidity and eliminate microorganisms, some of which can be vectors of disease. The process involves coagulation of the suspended matter followed by flocculation and sedimentation of these impurities(12).

Considering that *Moringa oleifera* seeds act as an important coagulant agent in water treatment. Given the above, the study aimed to develop methods of water treatment of the Negro River using *Moringa oleifera* seeds.

II. MATERIALS AND METHODS

This section explores the materials and methods obtained in the five phases: Section 2.1 Field work and samples; 2.2 Treatment of water with seeds of *Moringa oleifera;* 2.3 Optimization and preparation of simplified water treatment system; 2.4 Microbiological and physicochemical analysis and 2.5 Statistical analysis.

2.1. Field work and samples

The samples were collected in the Negro river, São Gabriel da Cachoeira, in the state of Amazonas between September and December 2018. The study was approved by the Ethics Committee of the Dean of Research, Graduate Studies and Innovation (PPGI), Federal Institute Amazonas (IFAM), and received funding from PPGI. The water samples were collected in four different locations: Orla da Praia, Praia do Jaú, Cosama and Tiago Montalvo *igarapé*. These sites were chosen because there are indigenous communities in these areas that make extensive direct and indirect use of water. Water samples were collected at each sampling point both directly and with the aid of sterile Van Dorn bottle samplers. All samples were collected in the morning, without the presence of rain for the past 48 hours. Then, they were treated and stored at 4ºC +/- 2ºC.

2.2. Treatment of water with seeds of Moringa oleifera

Moringa seeds were bought at Arbocenter Comércio de Sementes Ltda (Birigui, São Paulo). Tests were initially carried out to determine the quantity of seeds needed to reduce the turbidity and apparent color of water from the Negro River (Figure 1). A simplified procedure(13) for treating water with moringa seeds to improve the quality of water consumed in rural communities in the semi-arid region of Brazil was used. The first stage in the procedure was to remove the wings of the seeds while checking that the husks were neither dry nor discolored. The seeds were then crushed and ground to the consistency of a fine powder with the aid of a pestle.

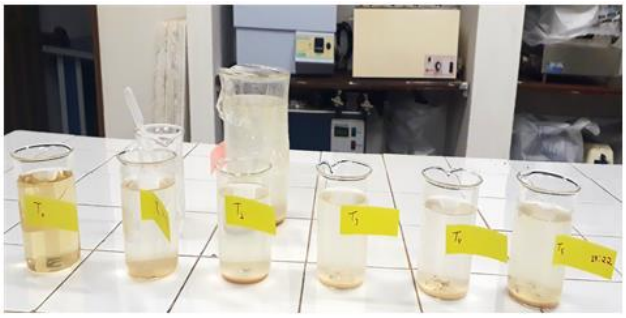

Fig. 1: Tests to determine the amount of moringa seeds needed for the water clarification process Source: Santos, (2018)

A ratio of 1 g of ground seeds to 1 L of untreated water was used. The untreated water collected was first placed in a 1 L beaker, to which 1 g of ground seeds was added. The mixture was stirred vigorously with a glass rod using circular movements for 2 minutes and more slowly for a further 15 minutes. At the end of this process, the water was left standing in the beaker for around 2 hours to allow

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the particles in suspension to coagulate and settle to the bottom. The water was then filtered with a paper filter and funnel to remove any remnants of the suspended seed powder (Figure 2).

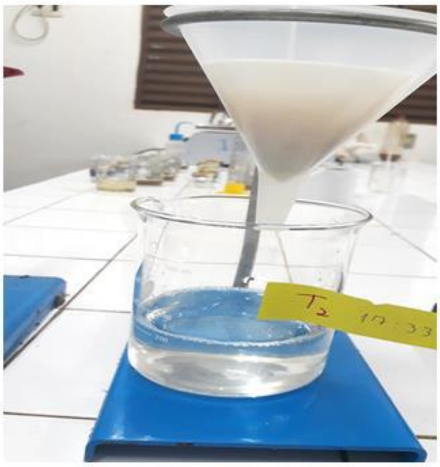

Fig. 2: Water being filtered with filter paper in a funnel after purification with moringa seeds
Source: Santos, (2018)

2.3 Optimization and preparation of simplified water treatment system

To improve the quality of the water purified with moringa seeds, four simplified filter-based water treatment systems were developed. The filters were made with affordable components that are readily available to indigenous communities. Each filter was constructed with a 5 L drum and had different material in the various layers.

Filter 1: a layer of 100 g of gravel + a layer of 200 g of activated açaí palm (*Euterpe oleracea*) seed charcoal + a layer of 100 g of gravel.

Filter 2: a layer of 100 g of gravel + a layer of 200 g of activated açaí palm seed charcoal + a layer of 100 g of gravel + a layer of 200 g of crushed brick.

Filter 3: a layer of 100 g of gravel + a layer of 200 g of activated plant charcoal + a layer of 100 g of gravel.

Filter 4: a layer of 100 g of gravel + a layer of 200 g of activated plant charcoal + a layer of 100 g of gravel + a layer of 200 g of crushed brick.

The gravel and bricks were cleaned with running water and left to dry in direct sunlight for 48 hours. The activated charcoal was produced by high-temperature physical activation in a brick and mud kiln-furnace designed for high-temperature use. A temperature of 720 ºC and heating time of 3 hours were used to produce the açaí palm seed charcoal. For the plant charcoal, which was made from coconut shell waste and wood, a temperature of 470 ºC and heating time of 3 hours were used. All the filters were produced and all the water treatment experiments with moringa seeds were carried out in the chemistry laboratory on the São Gabriel da Cachoeira campus of the Federal Institute of Amazonas. However, because the facilities in the laboratory were limited, it was not possible to perform a detailed microbiological and physicochemical analysis.

2.4. Microbiological and physicochemical analysis

All the samples used (raw samples, samples purified with moringa seeds and samples processed with the simplified filter-based treatment) were analyzed at Lupa Análises Bromatológicas Ltda., a specialized sciences laboratory in Manaus, Amazonas. The microbiological and physicochemical analyses followed the American Public Health Association "Standard Methods for the Examination of Water and WasteWater". In the microbiological analysis, the presence of total coliforms and *Escherichia coli* was investigated. The physicochemical analysis covered sensory parameters (apparent color, odor, taste, temperature) and physicochemical parameters (pH, turbidity, total dissolved solids, total hardness, total alkalinity, electrical conductivity, total iron, chloride and ammonia). The results were compared with the values specified in Brazilian Ministry of Health directive no. 2.914/2011 and consolidated in directive no. 05/2017[(14,15)].

2.5. Statistical analysis

A descriptive analysis of the results was performed and included the following measures: minimum, maximum, mean, standard deviation, coefficient of variation and quartiles[(16)]. The data were assessed by collection point and treatment. The five treatments were: purification with moringa seeds alone and purification with moringa seeds followed by one of four simplified filter-based systems. Each treatment was performed four times.

The non-parametric Wilcoxon-Mann-Whitney test was used to test for statistically significant differences between the results for treated and untreated samples, and the results were then compared with the values stipulated by the Brazilian Ministry of Health. A significance level of $p<0.10$ was used[(17)]. The statistical analysis was performed with software R version 3.6.1[(18)] in RStudio version 1.1.463.

III. RESULTS

A total of 84 water samples were analyzed. The following variables were used: total coliforms, E. coli, pH, turbidity, total dissolved solids, total hardness, total alkalinity, electrical conductivity, total iron, chloride and

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ammonia. The results obtained with the applied treatments show that there was a difference in the apparent color of the water, both with the use of *Moringa oleifera* alone and with the application of the simplified filter system (Figures 3 and 4).

Fig. 3: Comparison of untreated water (left) and water treated only with moringa seeds (right).
Source: Santos, (2018)

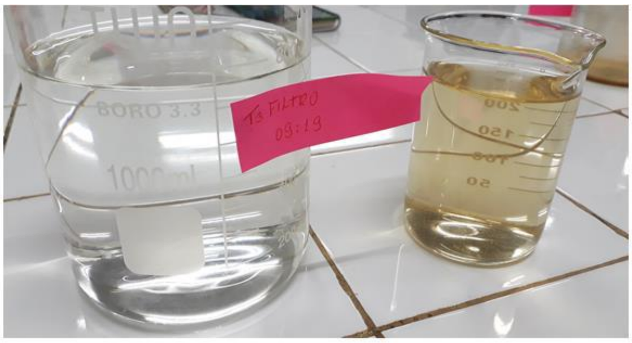

Fig. 4: Comparison of untreated water (right) and water treated with moringa seeds and TR3 (left).
Source: Santos, (2018)

The water samples had five different treatments to identify the best result for each collection point. We consider a raw sample for each collection point, that is, untreated water such as (TR0). The five treatments were: treatment only with M. oleifera seeds (TR1); treatment with M. oleifera seeds and filter 1 (TR2); treatment with M. oleifera seeds and filter 2 (TR3); treatment with M. oleifera seeds and filter 3 (TR4); and treatment with M. oleifera seeds and filter 4 (TR5). All treatments were performed four times, and the values of the variables for the treated samples were compared with the corresponding values for the untreated samples (Table 1).

Table 2 shows a comparison of treated and untreated samples collected at Orla da Praia. In a Wilcoxon-Mann-Whitney test with a significance level of $p<0.10$, the differences in the variables pH (p = 0.098), total dissolved solids (p = 0.098), electrical conductivity (p = 0.098) and turbidity (p = 0.098) were statistically significant for TR1 while for TR2 the differences in the variables (p = 0.098), total hardness (p = 0.089), pH (p = 0.098) and total alkalinity (p = 0.098) were statistically significant.

For TR3, the values of the variables turbidity (p = 0.098) and total hardness (p = 0.098) were significantly lower than the corresponding values for the untreated sample. The values of the variables total alkalinity (p = 0.098) and chloride (p = 0.089) were significantly higher. For TR4, only two variables had significantly different values: color (p = 0.098), for which the average was significantly lower than the value for the untreated sample, and total dissolved solids (p = 0.098), for which the value was significantly higher. For TR5, the variables with statistically significant differences in values were total hardness (p = 0.098), turbidity (p = 0.098), total dissolved solids (p = 0.098), total alkalinity (p = 0.098) and ammonia (p = 0.098), as shown in Table 2.

As for the comparison of the results of the different treatments of the water collected in Orla da Praia, with the values stipulated by the Ministry of Health of Brazil for water destined for human consumption, we identified that the pH was not within the normal values (corresponding pH to <9,5 and> 6) for none of the treatments used. In TR1 there were no statistically significant differences for electrical conductivity (p = 0.979) and ammonia (p = 1.0), while in the other treatments only ammonia showed a value that did not meet the normal values for drinking water stipulated by the Ministry of Health.

For samples collected at Praia Jaú and treated with TR1, the variables color (p = 0.098), turbidity (p = 0.098), total hardness (p = 0.098), total dissolved solids (p = 0.098), total alkalinity (p = 0.098), electrical conductivity (p = 0.098) and ammonia (p = 0.098) showed statistically significant values, different from the corresponding values for untreated water. For TR2, only the differences in the variables color (p = 0.098), total dissolved solids (p = 0.098) and total hardness (p = 0.098) were statistically significant. For TR3, the differences in the variables total hardness (p = 0.098), total alkalinity (p = 0.098) and ammonia (p = 0.089) were significant. For TR4, the variables with significantly different values were total dissolved solids (p = 0.098), total alkalinity (p = 0.089), electrical conductivity (p = 0.098) and ammonia (p = 0.098). For TR5, the variables pH (p = 0.098), total dissolved solids (p = 0.098) and electrical conductivity (p = 0.098) showed significant differences (Table 3).

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Table. 1: Values for untreated samples from each collection point.

Variables	OP	PJ	COS	TMI
Total coliforms (NMP/100ml)	0.00	100.00	0.00	0.00
Escherichia Coli (NMP/100ml)	0.00	100.00	0.00	0.00
Color (uH)	135.00	130.00	160.00	235.00
Odour (Intensity)	0.00	0.00	0.00	0.00
Taste (Intensity)	0.00	0.00	0.00	0.00
Temperature (ºC)	0.00	0.00	0.00	0.00
pH (-)	5.00	3.13	2.87	3.48
Turbidity (NTU)	1.74	2.26	1.87	4.52
Total dissolved solids (mg/L)	7.00	6.00	9.00	8.00
Total hardness (mg/L)	2.40	2.64	1.39	1.34
Total alkalinity (mg/L)	0.38	0.30	0.32	0.35
Electrical conductivity (*u*S/cm)	14.00	13.00	18.00	15.00
Total iron (mg/L)	0.24	0.00	0.28	0.00
Chloride (mg/L)	6.87	4.67	5.17	5.67
Ammonia (mg/L)	0.41	0.43	0.62	0.45

Collection points: OP = Orla da Praia; PJ = Praia Jaú; COS = Cosama; TMI = Tiago Montalvo *igarapé*.

Table. 2: Comparison of parameters for treated and untreated samples collected at Orla da Praia.

Variables	TR0	TR1		TR2		TR3		TR4		TR5	
		Mean	*p*-value	Mean	*p*-value	Mean	*p*-value	Mean	*p*-value	Mean	*p*-value
Color (uH)	135.00	5.18	0.125	5.08	0.098*	5.65	0.125	5.73	0.098*	6.23	0.125
pH (-)	5.00	5.53	0.098*	5.30	0.098*	5.13	0.174	5.15	0.149	5.45	0.125
Turbidity (NTU)	1.74	0.79	0.098*	0.49	0.125	0.76	0.098*	0.90	0.125	0.69	0.098*
Total dissolved solids (mg/L)	7.00	103.50	0.098*	64.75	0.125	49.00	0.125	70.75	0.098*	67.75	0.098*
Total hardness (mg/L)	2.40	2.07	0.125	2.03	0.089*	1.61	0.098*	2.57	0.625	2.18	0.098*
Total alkalinity (mg/L)	0.38	0.71	0.125	0.63	0.098*	0.48	0.098*	0.61	0.125	0.53	0.098*
Electrical conductivity (*u*S/cm)	14.00	209.25	0.098*	136.00	0.125	96.75	0.125	185.25	0.125	132.00	0.125
Chloride (mg/L)	6.87	12.50	0.125	9.59	0.125	7.81	0.089*	13.78	0.125	11.98	0.125
Ammonia (mg/L)	0.41	2.41	0.125	1.50	0.125	3.35	0.125	2.53	0.125	3.33	0.098*

Values are expressed as means. *p*-value ($p < 0.10$). *Statistically significant difference between values for treated and untreated samples.

Table. 3: Comparison of parameters for treated and untreated samples collected at Praia Jaú.

Variables	TR0	TR1		TR2		TR3		TR4		TR5	
		Mean	*p*-value	Mean	*p*-value	Mean	*p*-value	Mean	*p*-value	Mean	*p*-value
Color (uH)	130.00	5.73	0.098*	7.60	0.098*	8.43	0.125	10.00	0.125	8.25	0.125
pH (-)	3.13	3.83	0.125	4.79	0.125	4.40	0.125	4.99	0.125	4.75	0.098*
Turbidity (NTU)	2.26	0.87	0.098*	0.63	0.125	0.67	0.125	0.63	0.125	0.79	0.125
Total dissolved solids (mg/L)	6.00	49.00	0.098*	53.75	0.098*	80.75	0.125	67.25	0.098*	88.75	0.098*
Total hardness (mg/L)	2.64	1.96	0.098*	1.63	0.098*	2.08	0.098*	1.68	0.125	2.72	0.875
Total alkalinity (mg/L)	0.30	0.36	0.098*	0.35	0.125	0.48	0.098*	0.41	0.089*	0.35	0.125
Electrical conductivity (*u*S/cm)	13.00	97.75	0.098*	104.25	0.125	206.75	0.125	77.75	0.098*	89.75	0.098*
Chloride (mg/L)	4.67	6.98	0.125	4.99	0.625	4.60	1.000	4.65	0.854	5.07	0.125
Ammonia (mg/L)	0.43	3.80	0.098*	1.18	0.125	2.80	0.089*	2.61	0.098*	2.48	0.125

Values are expressed as means. *p*-value ($p < 0.10$). *Statistically significant difference between values for treated and untreated samples.

The comparison of the results of the different treatments of the water collected at Praia Jaú and the values stipulated by the Ministry of Health of Brazil for water intended for human consumption revealed that the pH was not within the normal values for any of the treatments. Significant differences in the following physical-chemical parameters of the treated water were observed for the TR1, TR2, TR4 and TR5 treatments: color, turbidity, total dissolved solids, total hardness, total alkalinity, electrical conductivity and chloride content. In TR3 the values of electrical conductivity ($p = 1.0$) and ammonia (p = 0.981) were higher than the values of drinking water stipulated by the Ministry of Health. The ammonia content ($p = 0.063$) was similar to the normal value only for TR2. There were no statistically significant differences for ammonia for the other treatments.

For the water collected in Cosama TR1 (Table 4), the differences in the variables total alkalinity ($p = 0.098$), total hardness ($p = 0.098$) and chloride ($p = 0.089$) were statistically significant. For TR2, only the turbidity variable ($p = 0.098$) had a significantly lower value than the corresponding value for the untreated sample, while for TR3 the differences in the color ($p = 0.098$) and ammonia ($p = 0.098$) variables were statistically significant. For TR4, only total dissolved solids ($p = 0.098$) showed significantly different values. For TR5, the differences in only two variables were significant: color ($p = 0.098$) and total dissolved solids ($p = 0.098$).

The comparison of the variables of the samples from the Cosama collection point with the normal values for human consumption revealed that there was a significant difference in pH for treatments TR2 and TR4. TR2 resulted in values within the normal parameters for most variables, according to the values for drinking water stipulated by the Ministry of Health. In TR1 the variables color ($p = 0.605$) and ammonia ($p = 1.0$) did not differ significantly , while in TR3 only ammonia ($p = 1.828$) presented values above that stipulated by the Ministry of Health. Likewise, in TR4 only color ($p = 1.0$), turbidity ($p = 1.0$) and electrical conductivity ($p = 1.0$) and in TR5 only turbidity ($p = 1.0$), electrical conductivity ($p = 1.0$) and ammonia ($p = 1.0$) presented values above the parameters established by the Ministry of Health.

Table 5 shows a comparison between the treated samples and the untreated samples collected in Tiago Montalvo *igarapé*. For TR1, the values of the variables total hardness ($p = 0.098$) and ammonia ($p = 0.098$) were significantly different from those corresponding to untreated samples. For TR2, the variables total hardness ($p = 0.098$), electrical conductivity ($p = 0.095$) and ammonia ($p = 0.098$) showed significantly different values. For TR3 the variables with significance were: turbidity ($p = 0.095$), pH ($p = 0.095$), total dissolved solids ($p = 0.098$) and total hardness ($p = 0.098$). For TR4, the variables with significantly different values were turbidity ($p = 0.098$), total dissolved solids ($p = 0.098$), total alkalinity ($p = 0.098$) and electrical conductivity ($p = 0.098$). For TR5,

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the values of the variables total hardness (p = 0.098), total alkalinity (p = 0.098) and electrical conductivity (p = 0.098) showed significant differences in relation to the corresponding values for untreated water.

Table. 4: Comparison of parameters for treated and untreated samples collected at Cosama.

Variables	TR0	TR1		TR2		TR3		TR4		TR5	
		Mean	*p*-value	Mean	*p*-value	Mean	*p*-value	Mean	*p*-value	Mean	*p*-value
Color (uH)	160.00	20.50	0.125	9.90	0.125	5.95	0.098*	66.25	0.125	12.75	0.098*
pH (-)	2.87	5.39	0.125	6.30	0.125	4.68	0.125	7.42	0.125	5.41	0.125
Turbidity (NTU)	1.87	0.87	0.125	0.34	0.098*	0.56	0.125	4.38	0.125	1.30	0.125
Total dissolved solids (mg/L)	9.00	42.00	0.125	36.00	0.125	36.75	0.125	222.00	0.098*	245.75	0.098*
Total hardness (mg/L)	1.39	1.75	0.098*	1.20	0.125	1.74	0.125	2.46	0.125	1.89	0.125
Total alkalinity (mg/L)	0.32	0.29	0.098*	0.30	0.181	0.46	0.125	3.13	0.125	0.47	0.125
Electrical conductivity (*u*S/cm)	18.00	83.75	0.125	66.00	0.125	71.00	0.125	453.00	0.125	490.50	0.125
Chloride (mg/L)	5.17	8.60	0.098*	6.05	0.125	8.47	0.125	42.50	0.125	44.75	0.125
Ammonia (mg/L)	0.62	2.06	0.125	1.22	0.125	1.83	0.098*	1.36	0.125	2.47	0.125

Values are expressed as means. *p*-value ($p < 0.10$). *Statistically significant difference between values for treated and untreated samples.

Table. 5: Comparison of parameters for treated and untreated samples collected at Tiago Montalvo.

Variables	TR0	TR1		TR2		TR3		TR4		TR5	
		Mean	*p*-value	Mean	*p*-value	Mean	*p*-value	Mean	*p*-value	Mean	*p*-value
Color (uH)	235.00	5.40	0.125	4.30	0.125	6.03	0.125	6.06	0.125	5.40	0.125
pH (-)	3.48	4.47	0.125	5.58	0.125	4.39	0.098*	5.33	0.125	5.17	0.125
Turbidity (NTU)	4.52	0.17	0.125	0.22	0.125	0.48	0.098*	0.38	0.098*	0.67	0.125
Total dissolved solids (mg/L)	8.00	47.75	0.125	31.75	0.125	55.25	0.098*	84.00	0.098*	163.00	0.125
Total hardness (mg/L)	1.34	1.68	0.098*	1.73	0.098*	1.36	0.098*	1.93	0.098*	2.10	0.098*
Total alkalinity (mg/L)	0.35	0.48	0.125	0.62	0.125	0.53	0.125	0.44	0.098*	0.54	0.098*
Electrical conductivity (*u*S/cm)	15.00	93.25	0.125	70.50	0.098*	84.75	0.125	135.25	0.098*	331.75	0.098*
Chloride (mg/L)	5.67	7.48	0.125	6.08	0.125	9.24	0.125	13.35	0.125	16.64	0.125
Ammonia (mg/L)	0.45	3.38	0.098*	1.66	0.098*	2.17	0.125	2.25	0.125	2.33	0.125

Values are expressed as means. *p*-value ($p < 0.10$). *Statistically significant difference between values for treated and untreated samples.

Comparison of the values of the variables of the samples collected in the Tiago Montalvo *igarapé* with the normal values established by the Ministry of Health, revealed that none of the treatments resulted in acceptable

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pH values, since the pH after all treatments was significantly below the value stipulated by the Ministry of Health. Of the other variables, ammonia ($p = 1.0$) was not significant in any of the treatments, except TR5, for which electrical conductivity ($p = 0.979$) was also not significant.

IV. DISCUSSION

The process used here to treat water from the Negro River with moringa seeds is time consuming as two hours are needed to clarify the water. If less time is allowed for the purification process, the seed particles do not adsorb enough particles of dirt to acquire the necessary mass and settle under gravity. With increasing time, more dirt adheres to the seed particles, settling at the bottom and leaving clean water, which can then be decanted(19). After various tests, it was found in the present study that optimal clarification was achieved with 1 g of moringa seed powder for every liter of untreated water. In a similar study on the purification of river water for rural communities with moringa seeds, it was shown that the minimum quantity of powder needed to reduce the turbidity of untreated water to 3 NTU (nephelometric turbidity units) was 0.25 g/L(19). This difference can be explained by the characteristic dark color of water in the Negro River, making it necessary to add more moringa seed powder to achieve adequate clarification. Another study reported that the reduction in protein content of moringa seed from 47% to 38% after use for water purification confirms the efficacy of these seeds as a clarifying agent in water treatment. This property can be attributed to a cationic protein in the seed that neutralizes the negative charges on particles suspended in the water, which aggregate to form flocs and then settle at the bottom of the liquid(20).

In an attempt to optimize the results achieved using only moringa seeds, we implemented simplified filter systems in order to obtain better values for parameters whose values changed after treatment, such as pH. A previous study showed that treatment of water with *M. oleifera* seeds has a very limited effect on pH, alkalinity and conductivity(20). Each water sample was therefore treated with moringa seeds alone and with moringa seeds together with the filters we developed.

The results of the microbiological and physical-chemical analyzes of the untreated water samples from Praia Jaú were the only collection point where total coliforms and E. coli were present in the untreated water. After the treatments applied with the moringa seeds and the filters, there was an absence of total coliforms and E. coli in the analyzed samples. These findings are important, however, additional and more detailed studies are needed to demonstrate the effectiveness of moringa seeds in eliminating pathogens from water. Studies show that moringa seed extracts have antimicrobial properties against various bacterial pathogens, including E. coli.(21,22).

The descriptive analysis evaluated statistically significant differences between the results of the samples from each collection point treated with each of the five treatments and the results of the untreated samples. For Orla da Praia, TR5 had the best result with statistically significant differences with a 90% confidence level for the following variables (see Table 2): total hardness ($p < 0.10$), turbidity ($p < 0.10$), solids total dissolved ($p < 0.10$), total alkalinity ($p < 0.10$) and ammonia ($p < 0.10$). For Praia Jaú, the treatment with the greatest statistical significance was TR1. The results for only two variables (pH and chloride) were not statistically significant ($p > 0.10$) (see Table 3), and all other variables had values ($p < 0.10$), indicating that this treatment had better significance at this collection point.

For samples collected at Cosama, there were few statistically significant differences when the results were compared with the values for untreated water. For TR1, three variables (total alkalinity, total hardness and chloride) had statistically significant differences while the other treatments only had one or two variables with statistically significant differences (see Table 4). In contrast, better results were observed for five variables with samples collected at Tiago Montalvo *igarapé* and purified with TR4 (see Table 5): turbidity, total dissolved solids, total hardness, total alkalinity and electrical conductivity. Also worthy of note was TR3, which resulted in a statistically significant difference for pH ($p < 0.10$), and TR1 and TR2, which yielded statistically significant differences for ammonia, unlike TR4. These findings suggest that by combining the components of the filters better results could be obtained.

This study consistently showed that the treatments used with the samples from the four collection points produced parameter values that were significant when compared with the corresponding values stipulated in ordinance no. 5, October 3, 2017. We found that pH and ammonia were the parameters whose values were more distant from the values for drinking water stipulated by the Ministry of Health. For most treatments, the ammonia content was above the level considered normal for drinking water, while the pH was significantly below the recommended value.

We found limited evidence of normal pH values and ammonia content for the treatments used. The ammonia

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content was normal for samples collected at Praia Jaú and treated with TR2 and for samples collected at Cosama and treated with TR2 and TR4. The comparison of the variables submitted to the TR1 of the samples at the Praia Jaú collection point with the normal drinking water values established by the Ministry of Health, revealed that most of the parameters met the values stipulated in ordinance no. 5, 2017.15. These results suggest the possibility of alternative sustainable methods that can be used to treat the waters of the Rio Negro.

Various studies have shown that the use of moringa seeds together with another simplified purification process can improve the quality of surface waters used for human consumption. For example, Keogh et al.,[23] investigating the natural coagulant action of *M. oleifera* as a pretreatment for solar disinfection of water, found that the powdered seeds of this plant can be used to produce water with low turbidity and that solar disinfection helps to inactivate bacteria. Another study investigated the use of moringa seeds to purify river water for domestic use in rural communities. The author used powdered moringa seeds as a natural coagulant and flocculant to clarify turbid water and copper as an antibacterial agent[19]. An earlier study also used moringa seeds to treat surface waters by slow direct filtration in synthetic non-woven blanket filters and simple sedimentation. The authors found that the coagulant properties of moringa seeds were effective in treating surface waters both by simple sedimentation and by slow direct filtration in synthetic non-woven blanket filters[24].

Overall, our results are encouraging as they show that treatment of samples from Praia Jaú with only moringa seeds (TR1) had an effect on the microbiological parameters and most of the physicochemical parameters. The results indicate that according to accepted guidelines, water from the Negro River treated as described here is more suitable for human consumption than untreated water. Our results indicate that moringa seeds are a sustainable, low-cost alternative for treating water for human consumption in indigenous communities that drink water directly from the Negro River without any type of treatment. This alternative thus helps to meet the daily needs of these communities. Had a different study design been adopted and more samples collected, more conclusive results might have been obtained. Further studies are therefore needed to confirm the findings presented here.

One of the main strengths of this study is that treatment of water using moringa seeds is a low-cost solution that does not require electricity and can be used in municipalities in the north of the state of Amazonas. Although the plant is not typical of the region, it can adapt to a wide variety of soils. During this study, we found that *Moringa oleifera* Lam. adapts to the soils found in the municipality of São Gabriel da Cachoeira, in the state of Amazonas. The use of moringa seeds may be a viable, simple solution for treating surface waters to supply the population[25]. That way, better quality water for human consumption can be produced, particularly for people living in indigenous communities far from urban areas and without access to any type of water treatment.

However, our study has some important limitations. As the samples were relatively small, robust data could not be obtained. It was not possible to use a larger sample because we were limited to the funds made available under the PPGI/IFAM call for projects. Furthermore, the samples had to be sent to a specialized laboratory in Manaus for the microbiological and physicochemical analyses as the town of São Gabriel da Cachoeira does not have a laboratory where this type of procedure can be carried out and we did not have the necessary equipment to perform the analyses. Another limitation was a logistical one as the town of São Gabriel da Cachoeira is in a region that is not easily reached, making it difficult to carry out large-scale studies.

A positive feature of this study is that it was based on studies in Brazil and other countries in which the authors showed the effectiveness of moringa seeds in the treatment surface waters[13,23,26,27,28,29] . Furthermore, this study is a novel one as there are to our knowledge no studies on the use of moringa seeds with water from the Negro River in the São Gabriel da Cachoeira region. Further studies using moringa seeds to treat water from the Negro River are needed to enable comparisons to be made and the results of the present study to be validated.

V. CONCLUSION

This study on the use of seeds of M. *oleifera* act as an important coagulant and can clarify the waters of the Negro River. The results of this research show that, when water is treated with moringa seeds, there are improvements in some parameters when compared to raw water, however, needs further investigation. In addition, this study compared the results of water samples treated with filtration systems with the normal values of drinking water parameters and found significant differences, suggesting the possibility of using these systems in the treatment of water for indigenous communities. In view of the lack of studies on the use of M. *oleifera* seeds with water from the Negro River, we reinforce the need for further research on the subject.

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