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Water Quality in Small-Scale Coffee Production Units, Amazonas, Peru

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Abstract: The objective of this research was to determine water quality in small-scale coffee production units in the Amazon Region, Peru. The characterization of the factors associated with coffee farmers was collected through surveys. The Standard Methods for the Examination of Water and Wastewater (APHA) method was used to determine the physicochemical and microbiological parameters of the incoming water (AE) (water for human consumption) and the outgoing water (AS) (wastewater from coffee washing). The results indicated that the coffee growers do not have adequate technology for washing the coffee and that they use water for these activities. In the characterization of the water, significant differences were found between the parameters of the AE and the AS, where the pH of the AE ranged from 7.00 to 7.32 and the pH of the AS from 3.76 to 4.44. The turbidity of the AS showed high values of 1814.47 NTU. Total Coliforms (TC) and heavy metals such as copper and chromium all increased in value up to 0.20 and 0.15 ppm in the AS compared to the AE. The characteristics of the water quality consumed by the coffee growers are poor and values above Peruvian standards were found.

Keywords: Coffee Fermentation, Water Quality, Coffee Growers, Technology

Introduction

Farmers are exposed to perceived economic, health, and lifestyle risks reflected in water quality (Bohnet, 2015). Areas with polluted water are a high health risk compared to less polluted areas (Withanachchi *et al*., 2018). During the last years, the deterioration of drinking water in rural areas has increased (Yermolenko *et al*., 2021), so the state has the responsibility to improve water quality (Miranda *et al*., 2010).

The wet milling of coffee generates coffee honey water with high organic matter content, directly impacting water, flora, fauna, and soils (Torres-Valenzuela *et al*., 2019). Water quality conditions for coffee washing are deficient, the parameters are not standardized, and coffee growers extract water from nearby streams or others (Akenroye *et al*., 2021). It is also known that large volumes of water are used during coffee washing, generating associated socio-environmental impacts on water bodies (Ruiz-Najera *et al*., 2021). In this sense, economic and easy-to-apply technologies should be adopted (Hernández-Sarabia *et al*., 2021). An important factor is training in good coffee washing practices, through modified tanks that provide good water use during washing (Lopez Blanco, 2014). Water quality and bad practices in coffee washing influence the quality of the coffee bean and as a consequence, the loss of income is devalued by its quality (Fernández-Cortés *et al*., 2020). Agricultural technologies have technical and environmental advantages; however, the high cost of the technology and the economic conditions of producers make it impossible to mass-market them (Sanz *et al*., 2011).

In the Amazon region, water quality in small-scale coffee production units has not been studied. The quality of the water consumed by coffee growers is unknown and the characteristics of the residual water after coffee washing are unknown. Based on the above, the objective was to determine the quality of water in small-scale coffee production units in the districts of Cajaruro and Pisuquia, Amazonas region, Peru.

Materials and Methods

Location

The study was conducted in the hamlets of San Isidro and Nuevo Belén in the district of Cajaruro, which has 25,104 inhabitants (INEI, 2017). The selection of farms was carried out in the annexes of Paujamarca at 2069 masl and Milagros at an altitude of 2080 masl, belonging to the district of Pisuquia. While the towns of San Isidro are at an altitude of 990 masl, Nuevo Belen 985 masl (Fig. 1), these towns are located on the right bank of the Utcubamba River (Morales-Rojas *et al*., 2021). The soils of the selected farms present adequate physical characteristics to promote coffee growing, in terms of depth, texture, and structure (Minagri, 2019).

UTM coordinates were taken with GPS model GPSMAP 66i-GARMIN (Table 1). Coffee is one of the alternative crops in the Cajaruro district, with one of the main livelihood crops being maize (Aguilar Carranza, 2021). While the towns of Paujamarca and Milagros in the district of Pisuquia are characterized as being considered the main coffee producers in the province of Luya (Guevara Alvarado, 2014). Pisuquia has an estimated population of over 5 175 people (INEI, 2017).

Characterization of Small Coffee Farmers (Coffee Washing and Harvesting Practices)

Data were collected through surveys of small coffee farmers in the four selected communities in the Amazon region of Peru. The visits were made at the end of the 2021 coffee harvest (August and September). The surveys were composed of the following questions: What is your level of education? are you associated with a cooperative? what is the source of water for washing coffee? what is the technology used for washing coffee? is the water used for washing coffee the same as the water used for human consumption? how many hectares of coffee do you cultivate? what is the coffee production system? (What is the percentage of women's participation in the harvest? What is the cost of daily labor during the harvest? How many cans of coffee does a laborer harvest on average per day? How many hours is coffee left to ferment after pulping? How many cans of cherry coffee is a quintal? Is coffee the main subsistence crop? The survey was applied to those producers that cultivate more than half a hectare of coffee. The questionnaire was validated following the "Expert Judgment" guidelines.

Selection of Coffee Samples for Physicochemical and Microbiological Characterization

To standardize the coffee sample, half a can of cherry coffee (10 kg) was harvested from the selected coffee farms, pulped, and left to ferment for 12 h. The pulped coffee (1.5 kg) was used in a container with a capacity of 20 liters, the bucket was gauged with 15 liters of water, and from this residual water, called output water (AS), the sample was collected for physicochemical and microbiological analysis. Samples of the incoming water (AE) with which the coffee was washed were also collected.

To determine the physical, chemical, and microbiological parameters, water samples were taken at the inlet and outlet during the 2021 coffee season, during the months of March, April, May, and August. The collection, storage, and transfer of the samples, as well as the laboratory analysis, were carried out according to Apha (2017).

The pH was measured in situ with a Hanna multiparametric water meter model HI 98194, while samples for determining the physicochemical parameters of Electrical Conductivity (EC), turbidity, Dissolved Oxygen (DO), alkalinity, cadmium, copper, chromium, lead, and zinc was collected in transparent plastic containers. Samples for microbiological analysis of Total Coliforms (TC) were collected in properly sterilized glass bottles with a capacity of 500 mL. These were transported in a cooler with dry ice at a temperature of 5°C. The parameters were analyzed at the Water and Soil Laboratory of the Research Institute for Sustainable Development of Ceja de Selva (INDES-CES) of the National University Toribio Rodríguez de Mendoza (UNTRM). The AE results were compared with the water quality standard for human consumption (031-2010-SA). Likewise, the AS, a product of coffee washing, was compared with the environmental quality standards (ECA), given that these standards contemplate the concentration levels of elements, substances, and physical, chemical, and biological parameters present in the water as a receiving body.

Statistical Analysis

The surveys were processed using the Excel spreadsheet, expressed in bar graphs. For the experimental units, two measurements were made for each of the variables, the sample size was less than 30 and the population variance is unknown; therefore, a T-student test for related or paired samples was applied to determine the existence or not of statistically significant differences between the first and second group of observations. The software used was Minitab 17 (Custodio and Chanamé, 2016).

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Table 1: UTM coordinates the coffee farms for the districts of Cajaruro and Pisuquia, Amazonas

East	West	Altitude (msnm)	Sampling point
818083.00	9291738.598	2069	Paujarmarca
818224.00	9290765.000	2080	Milagros
8114289.64	9350273.020	990	San isidro
813782.05	9351152.890	985	Nuevo Belén

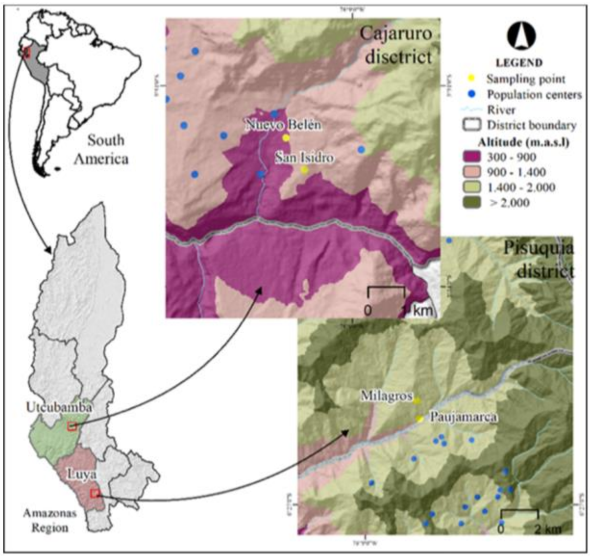

Fig. 1: Location map of the four coffee farms sampled

Results and Discussion

Characterization of the Evaluated Coffee Farms

The results of the characterization of the coffee growers evaluated show that 80% of the coffee growers have primary education and 20% have secondary education. All of the coffee growers in Nuevo Belén are not members of any cooperative, while Milagros and Paujamarca have 56 and 22% of members. The source of water used to wash the coffee comes from piped water in San Isidro and Nuevo Belén, and the water used for human consumption is the same water used to wash the coffee. Regarding the technology used to wash the coffee, 35% of the farmers use concrete tanks, while the majority of the population washes their coffee in the open air (sacks stored on the ground). In this sense, these should be improved, taking into account engineering, which has played an important role in developing technologies that have allowed water reduction (Oliveros-Tascón and Sanz-Uribe, 2011).

Table 2 shows that irrigated coffee production is minimal and even San Isidro does not have any irrigation. In the annexes of Milagros and Paujamarca, the participation of women in the coffee harvest ranges between 40 and 38.00% compared to San Isidro and Nuevo Belen, where the participation of women is 80%. Showing great similarity with the study by Martelo and Beutelspacher (2010), who mentions that women's participation in the coffee harvest was 86%, however, they are excluded from the benefits derived from commercialization and other personal development opportunities.

Harvest progress per laborer is 3-5 cans/day for the Milagros and Paujarmarca annexes. In San Isidro and Nuevo Belén it is 3-4 cans/day. Coffee fermentation in Milagros and Paujarmarca is usually left to ferment for an average of 18-24 h. In Nuevo Belén and San Isidro, the fermentation of pulped coffee ranges between 12 and 18 h. The amount of cans of cherry coffee needed to obtain a quintal of gold coffee (50 kg) is an average of 17 cans of cherry coffee for Milagros and Paujamarca. For Nuevo Belen and San Isidro, they need an average of 19 cans of cherry coffee to produce one quintal (50 kg). This may be influenced by altitudinal characteristics, as it has been shown that the higher the altitude, the higher the quality of the coffee (Martins *et al*., 2020).

Table 3 shows the descriptive statistics for the physicochemical and microbiological parameters, showing that the maximum pH of the AE was 7.27 and that of the AS was 4.44. The AE showed an alkaline pH, which may be due to the limestone that promotes the formation of carbonates and bicarbonates. The AS results show an acid pH, which is associated with the organic matter and dissolved solids in the coffee mucilage (Torres-Valenzuela *et al*., 2019).

The turbidity of the AS is high for all the sampled sites, reaching 1814.47 NTU. While for the AE the maximum value reached 9.17 NTU, a value that exceeds the water quality standard for human consumption. Turbidity values increased in the AS, which could be directly associated with the discharge of coffee mucilage, which contains suspended particles of different diameters (Fereja *et al*., 2020). The dissolved oxygen of the AE ranges from 7.29 to 7.83 mg/L, while for the AS it decreases its value to 0.19 mg/L. The decrease of DO in AS could be associated with coffee mucilage. Consequently, oxygenation systems should be included to degrade organic matter and not decrease the DO (Radzi *et al*., 2020). It is important to maintain the DO because it is important for living beings (Breitburg *et al*., 1997). Total coliforms showed high values in all samples; however, the highest values occurred in AS, reaching up to 4515.33 NMP/100 mL. The water consumed by the villagers is the same water used to wash the coffee and this water is contaminated by TC and heavy metals, which is above Supreme Decree N° 031-2010-SA. In this sense, it is necessary for the population to have access to safe water and basic sanitation, because it is known that the lack of these services conditions the presence of different types of diseases among small coffee growers (Cabezas, 2002). In Peru, especially the urban and rural population consumes piped water from different water sources, which is transported and stored in reservoirs where sometimes calcium hypochlorite solution is added as a disinfectant. It is then distributed through the piped network to households (Choque-Quispe *et al*., 2021).

The electrical conductivity of piped water for human consumption ranged between 30 and 1115 mS/cm. While coffee honey water values were higher, ranging between 938.67 and 1137 mS/cm. The electrical conductivity of water depends on the water temperature: The higher the temperature, the higher the electrical conductivity (Solís-Castro *et al*., 2018).

Alkalinity showed low values in AE, which is consumed by coffee farmers and is between 107.28 and 333.76 $CaCO_3$, compared to AS up to 27058.40 $CaCO_3$. The increase in alkalinity can be attributed to the effect of coffee mucilage, studies describe that alkalinity is determined by the ability to neutralize acids (Lecca, 2013).

The TC values ranged between 552.00 and 1600 NMP, these values correspond to the water of the four towns analyzed, which allowed determining the quality of the water, concerning the indicators of fecal contamination (Ishii and Sadowsky 2008). In that sense, water with TC generates infection in people, causing a significant health risk, for this they must perform a conventional or special type of treatment depending on the magnitude of contamination in both the AE and the AS for this, the Regulation of Water Quality for Human Consumption should be contemplated (DIGESA, 2010; Chibinda *et al*., 2017).

Concerning cadmium in the EC, high values were reported for San Isidro and Nuevo Belén. While for the AS the values decreased to 0.01 mg/L. Therefore, it is observed that the intake of water is the highest in cadmium and requires prevention measures since cadmium in the resources natural resources can pose a serious threat to the ecosystem and human health through the food web (Zhang *et al*., 2017). High concentrations can happen due to domestic and industrial activities, as well as urban (sewage) and agricultural runoff (Kilunga *et al*., 2017).

The highest copper values correspond to the AE in the towns of Paujamarca and Milagros, ranging from 0.22 to 0.16 mg/L. While the copper values for the AS were 0.01 mg/L. The presence of copper in coffee residues may occur due to the application of copper-based fungicides used in the control of coffee diseases and this also applies to the concentration of copper in nearby surface waters (Chanakya and De Alwis, 2004). Heavy metals, such as cadmium, copper, and chromium, are evidenced in the EC with lower values compared to the outflow water, which increases the values. It is important to note that the EC is above the water quality regulations for human consumption and that the AS is also above the environmental quality standards.

The lead had a marked behavior between AE and AS, having minimum values for AE with values of 0.02 mg/L and AS 0.28 mg/L. Drinking water can be a source of lead poisoning when acidic water is combined with a system of lead pipes, as well as lead naturally (Blanco Hernández *et al*., 1998). Lead can affect systems, organs, and tissues and its effect can be proportional to the amount present in the organism (Poma, 2013). Lead can also change the alkalinity of the soil and decrease its productivity and can even lead to desertification (Pamela *et al*., 2014).

Zinc in the EC showed minimum values of 0.01 mg/L, while the maximum value for the AS was 0.36 mg/L. The presence of zinc in drinking water above the permitted limits is considered hazardous to human health, the presence of zinc can be caused by anthropogenic activities including oil burning, industrialization, and urbanization (Zahra *et al*., 2015). Zinc also occurs naturally in the earth's crust and is considered a vital component necessary for plants in adequate concentrations (Futalan *et al*., 2019).

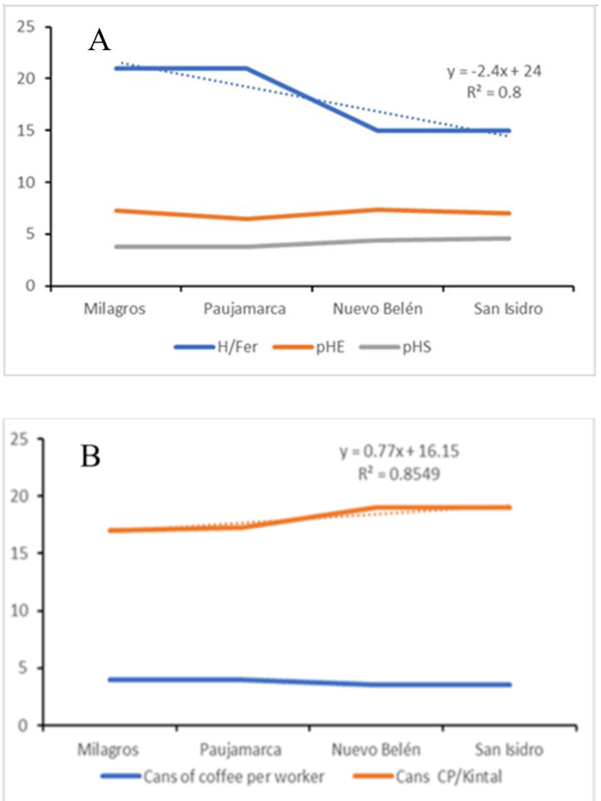

Fig. 2: Relationship of coffee fermentation hours with pH, H/Fer = Hours of fermentation of pulped coffee (A); Relationship between the number of cans of cherry coffee harvested per worker and the amount of dry coffee for the yield of one kintal.

Table 2: Coffee washing and harvesting characteristics

Characteristics of coffee growers	Milagros	Paujamarca	Nuevo Belén	San Isidro
Irrigated coffee production	37.50%	22.22%	11.11%	0%
Coffee production without irrigation	62.50%	77.78%	88.89%	100%
Women's participation in the harvest	40%	38.00%	60%	65%
Males in the harvest	60%	62.00%	40%	35%
Daily wage cost	S/20-30	S/20-30	S/20-30	S/20-30
Average number of harvested cans of coffee per worker	3-5 latas/día	3-5 latas/día	3-4 latas/día	3-4 latas/día
Fermentation hours after pulping	18-24 h	18-24 h	12-18 h	12-18 h
Cans of cherry coffee to obtain one quintal	17.00	17.300	19.00	19

Table 3: Results of the physicochemical and microbiological parameters (averages ± standard deviation)

Location	PM	pH (Unit)	Turbidity (NTU)	DO (mg/L)	EC (µS/cm)	Alkalinity (mg/L; CaCO3)	TC(NMP/ 100 mL)	Cadmium (mg/L)	Copper (mg/L)	Chrome (mg/L)	Lead (mg/L)	Zinc (mg/L)
M1	E	7.27±0.46	1.63±000.25	7.29±0.82	130.47±9.38	107.28±11.92	1600.00±000.00	0.01±0.00	0.02±0.01	0.01±0.00	0.02±0.02	0.01±0.01
	S	3.81±0.28	1814.47±661.51	0.30±0.13	938.67±165.39	12714.67±10750.05	1079.67±901.24	0.02±0.01	0.16±0.05	0.01±0.00	0.28±0.025	0.07±0.06
P1	E	6.50±0.65	9.17±8.47	7.31±0.72	753.00±5.58	99.33±38.32	1114.35±841.18	0.01±0.00	0.06±0.08	0.01±0.00	0.14±0.17	0.03±0.04
	S	3.76±0.23	3147.77±2005.22	0.26±0.15	1137.00±163.05	12714.67±10750.05	4515.33±6460.74	0.01±0.00	0.22±0.25	0.01±0.00	0.27±0.21	0.03±0.03
SI	E	7.00±0.36	0.40±000.46	7.53±0.62	1115.00±629.60	333.76±31.54	552.00±9007.61	0.01±0.00	0.02±0.01	0.01±0.00	0.12±0.04	0.02±0.01
	S	4.58±0.26	524.43±289.83	0.35±0.12	1215.53±274.70	27058.40±38582.34	1600.00±000.00	0.04±0.00	0.10±0.02	0.01±0.00	0.43±0.09	0.36±0.28
NB	E	7.32±0.21	1.43±000.90	7.83±0.05	753.00±5.58	313.89±13.76	114.67±158.77	0.01±0.00	0.01±0.01	0.04±0.06	0.07±0.06	0.02±0.01
	S	4.44±0.06	885.23±458.43	0.19±0.10	1137.00±165.05	9178.40±1278.64	1503.73±166.74	0.04±0.05	0.00	0.16±0.26	0.28±0.18	0.03±0.02
ACH	031-2010-SA	6.5 a 8.5	5.00	nc	1500.00	nc= < 1,8 /100 ml	0.003	2.00	0.05	0.01	3.00	
ECA	C (3): RV	6.5 – 8.5	nc	nc	ncnc	1 000	0.010	0.20	0.10	0.05	2.00	

ACH=A Regulation of Water Quality for Human Consumption; ECA=Environmental Quality Standards

Table 4: Correlation between parameters

Parameters	Correlation
pH1 and pH2	0.41286
Turbidity 1 and Turbidity 2	0.09231
DO1 and DO2	-0.31548
EC1 and EC2	0.77097
Alkalinity 1 and Alkalinity 2	0.26651
TC1 and TC2	-0.34714
Cadmium 1 and Cadmium 2	0.27406
Copper 1 and Copper 2	-0.40103
Chrome 1 and Chrome 2	0.99841
Lead 1 and Lead 2	-0.19485
Zinc 1 and Zinc 2	-0.03678

*Significant differences (alpha value)

Table 5: Significant differences in parameters

Matched differences parameters	Media	Confidence interval	Lower confidence interval upper	t	Sig. (bilateral)
pH1 - pH2	2.8750000	2.663535	3.086465	28.124657	0.000*
Turbidity 1- Turbidity 2	-1589.8167000	-2171.442532	-1008.190801	-5.654471	0.000*
DO1 - DO2	7.2150000	6.954084	7.475916	57.203683	0.000*
EC1 - EC2	-419.1833300	-554.859030	-283.507637	-6.391320	0.000*
Alkalinity 1 - Alkalinity 2	-15202.9670000	-23383.447758	-7022.485576	-3.844484	0.001*
TC1 - TC2	-1329.4300000	-2767.310546	108.450546	-1.912631	0.068^{ns}
Cadmium 1- Cadmium 2	-0.0187500	-0.035178	-0.002322	-2.361039	0.027^{ns}
Copper 1- Copper 2	-0.1241667	-0.181132	-0.067201	-4.509035	0.000*
Chrome 1 - Chrome 2	-0.0300000	-0.070339	0.010339	-1.538454	0.138^{ns}
Lead 1 - Lead 2	-0.2250000	-0.314211	-0.135789	-5.217367	0.000*
Zinc 1 - Zinc 2	-0.1008333	-0.179688	-0.021978	-2.645233	0.014^{ns}

*show significant differences (P<0.05); ns no significant differences (P>0.05)

Table 4 shows the correlation of physicochemical and microbiological parameters, where the correlation is positive for turbidity, pH, EC, Alkalinity, Cadmium, and Chromium. This reflects that the AE and AS parameters move in the same direction. Whereas DO, TC, Copper, Lead, and Zinc showed a negative correlation.

Table 5 shows the significant differences in the paired parameters, whereas for TC, Cadmium, and Chromium no significant differences are shown. However, all other parameters show significant differences.

Figure 2 shows the relationship between the average hours of coffee fermentation in both zones studied, where the r2 is 0.8 (Fig. 2A), as well as the relationship that exists between the amount of cherry coffee harvested per worker/day and the yield of dry coffee, the approximate relationship is 0.85 (Fig 2B). In relation to the hours of coffee fermentation, it is evident that the shorter the fermentation time the pH of the AS increases, studies mention that the pH is a function of the fermentation time and is a potentially reliable parameter to measure the progress and end point of fermentation (Lee *et al*., 2015).

Conclusion

Coffee syrup water proved to be contaminated for the water, by increasing the values of physicochemical and microbiological parameters. There were also significant differences between the parameters evaluated in both districts (Cajaruro and Pisuquia). From the characterization of the coffee growers, it was found that there are differences in the fermentation times for coffee washing, this may be conditioned to the altitude between the farms in the district of Cajaruro and Pisuquia, as well as the water consumed by the coffee growers is piped without potabilization, the same water is used for coffee washing. No treatment is applied to the AS and when it is discharged, it causes high contamination. Therefore, coffee growers should receive constant training on the impact that coffee processing generates on the environment, to raise their awareness.

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Author's Contributions

Eli Morales Rojas, Segundo Chávez Quintana and Magali García: Conceptualization, drafted, and revision of the final version.

Jaris Veneros and Manuel Oliva: Manuscript preparation, statistical analysis, and final version edited.

José Carlos Santa Cruz Guerrero: Designed and laboratory analysis of samples, and review of the final draft.

Manuel Emilio Milla Pino: Methodology, project management, resources, software, validation, and data visualization.

Alex Lenin Guivin Guadalupe and Tito Sanchez Santillan: Manuscript writing, data collection, analysis, and project management. Finally, all authors have read and accepted the final version of the manuscript.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all authors have read and approved the manuscript and that there are no ethical issues.

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