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Managing Coffee Processing Water in Hawaii

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ABSTRACT

Hawaii is the only state in the USA that grows, processes, and roasts coffee. Coffee processing, however, poses some challenges. One is the processing water, which must be treated, and should be re-used. We surveyed and collected several coffee processing water samples, both influent and effluent, from four small-scale (2-5 ha) coffee farms in Kona on Hawaii (Big Island), and from a large (1200 ha) coffee farm on Kauai. The samples were kept refrigerated during transport and storage. Subsamples were filtered and analyzed for biological oxygen demand (BOD), pH, and plant nutrient concentration. Aeration and lime ($CaCO_3$) were applied in an attempt to lower BOD and phosphorus (P). Our findings showed that the Kauai coffee effluent and its reuse (irrigation) is more environmentally friendly in terms of BOD and plant nutrients than those in Kona. This is perhaps because the Kauai processing uses the hydropulping technique, which does not involve fermentation. Farms in Kona use the wet fermentation technique to remove the mucilage from the parchment coffee. Aeration for 7 days with 1% lime helped reduced BOD to about 300 mg L^{-1} and P by several fold.

INTRODUCTION

Coffee industry is expanding in Hawaii, the only state in the United States that grows and processes coffee (Bittenbender and Smith, 2000). The crop has expanded in planting areas by almost 3-fold over the past decade, and generates nearly 25 million dollars per year in farm-gate receipts alone (Hawaii Agricultural Statistics, 2003). Kona coffee is quite well known around the world. As coffee production increases, however, the volume of processing (used) water resulted from the pulping and post fermentation-rinsing process also increases. A diagram of coffee processing water system is shown below (Fig. 1).

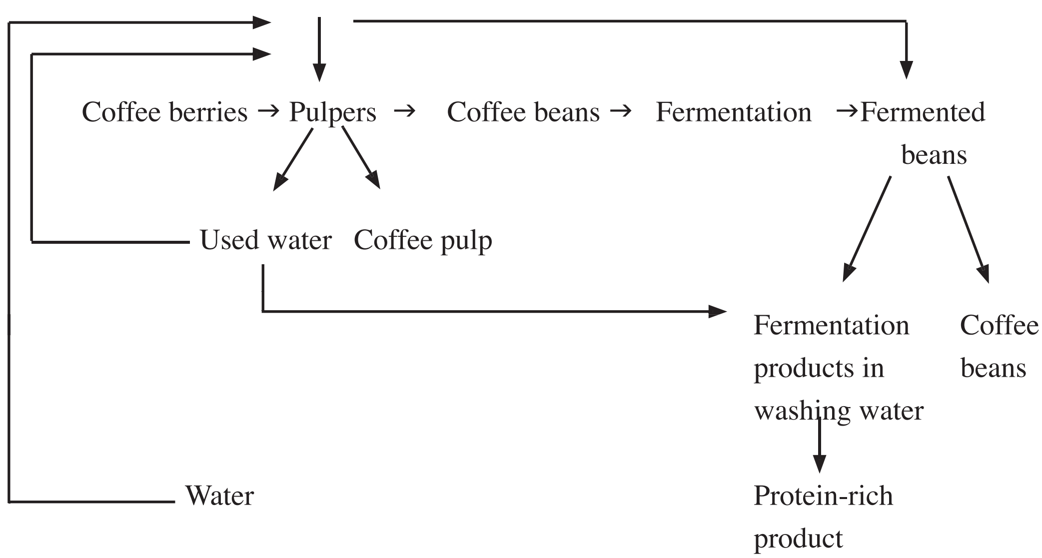

Fig. 1. Water usage in a coffee processing system using the wet fermentation method. (Adapted from Bressani, 1979)

On average, it requires about 5 – 15 liters of water to obtain 1 kg of clean green bean coffee (the actual volume of water used depends on the pulping process- fermentation or hydropulping- and how much water is used in transporting the coffee). As a practical example, a coffee orchard of about 200 ha requires about four million liters (20,000 L ha^{-1}) of water per season for the cherry (coffee fruit) processing operation (Dan Kuhn, Coffees of Hawaii, personal communication, 2000).

Since the coffee processing water is considered by the Hawaii's State Department of Health and the federal EPA as "non-domestic" processing water, it is not legal to discharge the water to the public sewer systems. Besides, the coffee processing water's high sugar content and biological oxygen demand (BOD) prevents good mixing with sewage water. It has been reported that coffee processing water can have a chemical oxygen demand, a measure of water soluble carbon, mostly sugars and proteins of 1.0 -5.0 % C L^{-1} (Bressani, 1979). Other discharge alternatives, such as to stream, ocean, dry ditch or injection well, are virtually impossible for coffee processing water because stringent regulations must be met as stated in Hawaii's laws: HAR 11-55 and HAR 11-23. Thus, the only practical alternative is to apply the processing water back to the orchard after treatment. Most coffee growers are aware of this irrigation alternative. Yet, there are problems, including (i) some trees have died from the processing water application, and (ii) odor and nuisance (flies, insects) are of noticeable concern (Hue and Bittenbender, 2003).

Our objectives were to characterize the chemistry of the coffee processing water from different orchards in Hawaii, and to treat the water for beneficial irrigation reuse with the purpose of reducing its BOD and its potential pollution.

MATERIALS AND METHODS

Coffee processing water collected from 4 small (2-5 ha) coffee farms' processing facilities in Kona, Hawaii provided 11 water samples (both influent and effluent). Another 9 samples were collected from a large coffee farm on Kauai at different locations during the washing/reusing operation. Samples were collected in 1-liter bottles, kept refrigerated during transport and storage before analysis.

Analysis included biological oxygen demand at 5 days (BOD_5), solution pH, and plant nutrients. Total suspended solids were also measured from the Kona water samples.

The method for BOD_5 measurement is briefly described as follows. The water samples were either undiluted (influents) or diluted 10 or 100 times (effluents) and mixed with deionized water in 300 mL specialized bottles. Buffer reagents and inorganic nutrients were added. Each sample solution was incubated at 25 ^{o}C for 5 days. The standards used were a combination of glucose and glutamic acid. An O_2 sensitive membrane electrode was used to measure O_2 concentration in the water before and after 5 days of incubation (Clesceri *et al*., 1995).

The procedures described by Hue *et al*. (2000) were used for other chemical preparation and analysis. An inductively coupled plasma (ICP) spectrometer was used to measure plant nutrients in the processing waters after filtering through a Whatmann No. 42 filter paper.

The treatment to lower BOD and P was conducted as follows. A 100 mL of coffee processing water was added to a 250- mL open top Erlenmeyer containing 1.0 g $CaCO_3$. The Erlenmeyer was shaken on a rotary shaker at 100 rpm for 7 days before filtering and analysis.

RESULTS AND DISCUSSION

Biological oxygen demand and pH of coffee processing waters.

The processing water samples from Kona (Table 1) had BOD ranging from 8,000 to 11,500 mg L^{-1}. These farms used the wet processing method –pulping, fermentation and rinsing. Kona influent water averaged only 12 mg L^{-1} BOD. In contrast, the Kauai facility used a hydro-pulping technique, which requires more water but no fermentation. Thus, its processing water, which is mostly recycled for irrigation, had on average a BOD of 800 mg L^{-1} and was lowered to about 300 mg L^{-1} after sand filtration (Table 1).

The influent waters were (expectedly) neutral: pH 6.6 – 7.9. However, after being used for coffee processing, the water pH dropped to between 3.5 and 4.5 likely because of organic acids in cherry skin and pulp. Since the water was not buffered, this drop in pH from approximately 7.0 to 4.0 may not be as alarming as the numbers might suggest. However, to increase microbial growth and activity for decreasing BOD, an upward pH adjustment must be considered.

The BOD and pH agree well with what reported by Cleves (2004).

Table1. Biological oxygen demand (BOD_5, mg L^{-1}) and processing water pH.

KONA			
Facility	Water description	BOD_5	pH
1	Influent (incoming)	13	6.72
	Water after pulping	8,000	3.54
2	Influent	10	7.15
	Cherry washing/pulping	11,000	4.22
	Washing/recirculation	11,000	3.79
	Effluent water	10,500	4.46
3	Influent	9	6.65
	After 14 h fermentation	11,500	3.78
4	Influent	15	6.89
	After pulping	10,500	4.07
	Filtered/treated effluent	30	6.55
KAUAI			
Location	Water description	BOD_5	pH
1	Influent	17	7.88
2	During hydropulping	795	4.25
3	After hydropulping	770	4.32
4	At treatment station for reuse	805	4.35
5	Discharge water at a holding pond (not for reuse)	765	7.20
6	Aerated pond	690	4.39
7	Holding pond before sand filtering	712	4.00
8	After sand filtration	325	5.07
9	At irrigation drip line	242	5.07

Plant nutrients in the coffee processing waters

Given the rich K in coffee cherries, marked increases in K concentration in coffee processing waters are not surprising (Table 2). For example, K concentrations increased from an average of 5.3 mg L^{-1} in the Kona area influent to about 700 mg L^{-1} after coffee processing. On Kauai, where hydropulping was used with greater water volume, the increase was slightly less: from 3.6 mg K L^{-1} in the influent to about 110 mg K L^{-1} in the reused effluent water. With such high K concentrations, a potential liquid K fertilizer could be assumed from the processing water, if properly managed.

To a lesser extent, the concentrations of Ca, Mg, and micronutrients (Cu, Mn, and Zn) were also increased in the processing water (Table 2). Elevated levels of these nutrients may be good for irrigation due to low concentrations of available Ca, and Zn in most soils used for coffee production in Hawaii (Hue, 2004).

In contrast, the increases in P in processing water are of concern (Table 2). Phosphorus concentration in the influent water was about 0.1 mg L^{-1}, meanwhile the effluent contained as much as 62 mg L^{-1}. We believe most of this P was in the organic forms, because we used ICP to measure total soluble P (after filtering). Nevertheless, these high P concentrations might need to be reduced if the processing water is to be discharged off the farm, as the EPA standard for total soluble P in water is 1.0 mg L^{-1}.

Treatment to decrease BOD and P in coffee processing waters from Kona

By bubbling air through the effluent amended with 1% lime, our results showed that we could significantly lower BOD (Figure 2) and P (Figure 3). It was speculated that saturated lime ($CaCO_3$) effluent under aerated conditions would raise the water pH to around 8.0, which would stimulate microbial activities. The results are a rapid conversion of organic C (BOD) to CO_2, and a mineralization of organic P to orthophosphate (mostly HPO_4^{2-}). The Ca levels in saturated effluent are about 600 mg L^{-1}, that would precipitate most soluble P as Ca-P, either as amorphous or minerals, depending on time and other solution conditions (e.g., ionic strength, competing ions, soluble organic molecules).

Table2. Plant nutrients (mg L^{-1}) in the coffee processing waters.

KONA

Facility	Water description	K	P	Ca	Mg	Cu	Mn	Zn
1	Incoming (influent)	5.9	0.10	--	--	0.04	0.02	0.01
	After pulping	590	13.0	--	--	0.36	0.50	0.90
2	Incoming	6.9	0.20	26	11	0.02	0.01	BD
	Cherry washing/pulping	310	9.5	300	100	0.68	0.25	0.14
	Washing/recirculation	200	8.4	275	99	0.66	0.21	0.14
	Effluent water	230	7.0	280	95	0.72	0.13	0.08
3	Incoming	3.9	0.10	27	12	0.02	BD	BD
	After 14 hr. fermentation	860	27.0	320	125	1.70	0.80	0.30
4	Incoming	4.6	0.10	28	12	0.03	0.02	BD
	After pulping	1680	62.0	365	165	1.82	1.40	0.24
	Filtered/treated effluent	13.1	0.10	220	90	1.00	0.02	BD

BD: Below detection limit

KAUAI

Location	Water description	K	P	Ca	Mg	Cu	Mn	Zn
1	Incoming	3.6	0.05	29.3	45.5	BD	0.02	0.02
2	During hydropulping	192	1.52	29.1	45.2	0.07	0.43	0.16
3	After hydropulping	103	0.75	28.5	47.0	0.04	0.28	0.05
4	At treatment station for reuse	143	0.70	30.0	43.3	0.07	0.30	0.10
5	Discharged water at a holding pond (not for reuse)	87	0.15	37.1	54.2	BD	0.29	0.01
6	Aerated pond	121	0.46	32.5	45.1	BD	0.14	0.05
7	Holding pond before sand filtering	120	0.45	31.5	45.0	BD	0.12	0.05
8	After sand filtration	60	0.07	29.0	41.3	BD	0.08	0.02
9	At irrigation drip line	59	0.13	28.6	41.4	BD	0.08	0.02

BD: Below detection limit

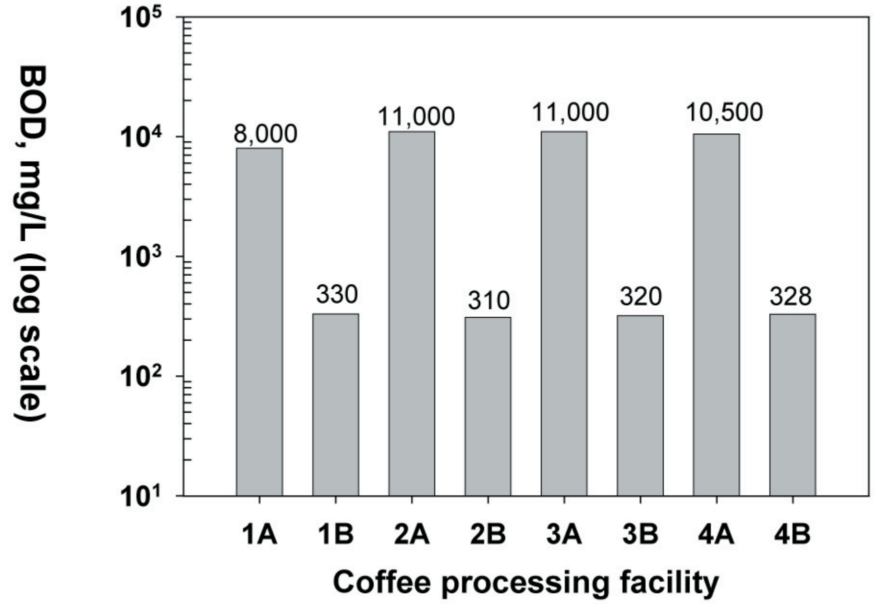

Figure 2. Biological oxygen demand (BOD) before (A) and after aeration for 7 days with 1% $CaCO_3$ added to the coffee processing waters (B). Numbers on top of the bars are actual concentrations.

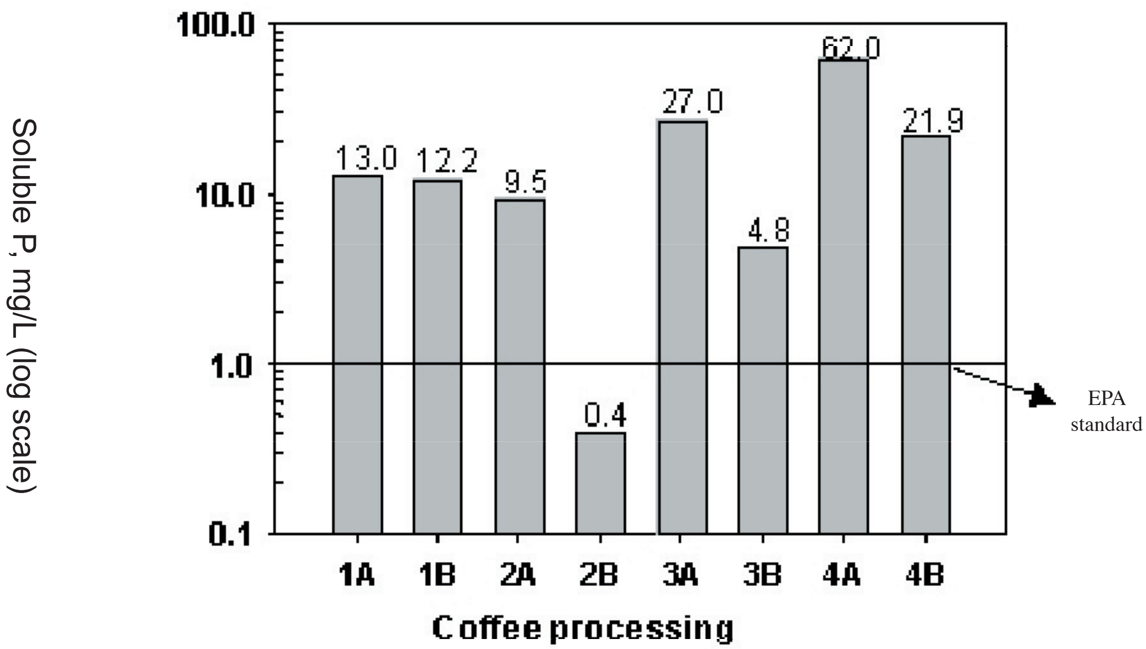

Fig. 3. Total soluble phosphorus concentration in the coffee processing waters: (A) before treatment, (B) after 7 days aeration with 1% $CaCO_3$ (saturated) added. Numbers on top of the bars are actual concentrations. The line indicates the EPA water quality standard of 1.0 mg P L^{-1}.

SUMMARY AND CONCLUSIONS

Coffee processing water, especially from small-scale facilities that use the wet fermentation process, is quite high in BOD (8,000 – 11, 500 mg L^{-1}). Such high BOD levels must be lowered to < 300 mg L^{-1} to reduce odor and insects. On the other hand, the water contains elevated levels of plant nutrients, noticeably K and P. This may be beneficial (irrigation reuse) or detrimental (disposal/discharge). Treatments with lime and aeration significantly lowered the BOD and P levels in the water.

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