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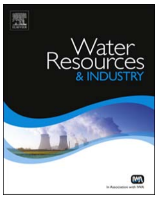

Characterization of effluent from food processing industries and stillage treatment trial with *Eichhornia crassipes* (Mart.) and *Panicum maximum* (Jacq.)

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ABSTRACT

In this study, effluents from 11 food processing industries from various sectors were characterized through analysis of physical and chemical parameters. In general, effluents pHs are between 4.07 and 7.63. Lead (Pb^{2+}) and cadmium (Cd^{+}) concentrations range from 0.083 to 1.025 mg/l and 0.052–0.158 mg/l respectively. The biodegradability of the effluent is very low. The principal component analysis (PCA) grouped industries according to their organic matter levels; thus, stillage, livestock, molasses and sugar refinery effluents show some similarities, as well as confectionery, oil mill, dairy and brewery effluents. Forms of nitrogen measured show low levels of nitrites (NO_2^-), high levels of nitrates (NO_3^-), ammonium ($NH_4^{+)}$ and Kjeldahl nitrogen (TKN). Among these effluents, a treatment trial with *Eichhornia crassipes* and *Panicum maximum* was applied to stillage effluent from Fermencam distillery. The results show that *Panicum maximum* and *Eichhornia crassipes* reduce pollutant loads of Fermencam's wastewater.

1. Introduction

Regardless of the size of food processing companies, their activities contribute to the economic development of countries in the world. To meet both the overall economic growth and food security targets of the population, sub-Saharan African countries focus more effort on food processing industry. Due to an exponential population growth, these developing countries experienced an increase of the basic needs of their population, resulting in agricultural development, over-exploitation of natural resources, uncontrolled urbanization and development of the industrial sector [1–3]. However, the consequences of this development based on economic growth which usually overlooks the environmental component are extremely serious. Meanwhile the creation of agro-industrial complexes provide certain economic advantages, the lack of proper management of effluent discharged may harm the quality of the environment [4].

In Cameroon, the food processing sector is important at the national level, given the number of companies and the industrial production. This sector is very active and provides essential services in the supply of various consumer products in major urban centers. However, the price to pay to meet the population needs is high, since it results in environmental

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pollution characterized by the uncontrolled discharge of food processing effluents into terrestrial and aquatic ecosystems [5–7]. These effluents come from a fairly diversified food processing sector such as brewing, dairy and sugar industries, distilleries, slaughterhouses, oil mills and sweet manufacturing. The dairy effluent discharge volume is high [8]; food processing industries consume large quantities of water and are therefore a nuisance to the environment. In Cameroon, 80% of these industries are found in the Littoral region, and the city of Douala provides a major contribution to the national and regional economy. But food processing industries are found in the ten regions of the country. The National Environment Management Plan in Cameroon prepared following a study on industrialization and industrial pollution of 147 units of industrial and artisanal processing units showed that the food processing industry contributes mostly to pollution, with an estimated biochemical oxygen demand (BOD_5) and suspended solids (SS) of 2187 tons/year and 48,000 tons/year respectively in Douala alone [9,10]. Indeed, effluents discharged into natural ecosystems contribute to the change in abiotic factors in the environment [11–14]. Chemical oxygen demand (COD) and biochemical oxygen demand (BOD_5) found in untreated effluents from food processing industries are usually high [15],with levels that may be 10–100 times higher than those of domestic wastewater [16–18].

The levels of suspended solids vary marginally, and untreated effluents from certain meat, fish, dairy and vegetable oil production sectors show high levels of oil and grease [15].

High phosphorus levels may also be found, in particular when large quantities of phosphoric acid are used in the degumming process of vegetable oils, or in the cleaning [19–22]. Dairy wastewaters are also characterized by wide range of pH values between 3.5 and 11 caused by the use of alkaline and acid cleaners and sanitizers [23]. The dairy industry generates strong wastewaters characterized by high concentrations of organics (BOD_5, COD), mainly carbohydrates, proteins and fats originating from the milk [23]. The wastewater production is frequently seasonal and since the dairy industry produces various products (milk, butter, yoghurt, ice cream, and cheese), the composition of the effluent varies according to the type of product and technology used.

Environment pollution has become a major concern worldwide. To address surface water pollution and protect ecosystems, wastewater needs to be treated in order to contribute to a cleaner environment. The treatment of wastewater requires the creation of wastewater treatment systems that are conventional in most cases (activated sludge, trickling filters, digesters, etc.) [24,25]. It is also worth exploring new industrial wastewater treatment technologies that are reliable and adapted to realities of developing countries. This is why the use of plant-based systems is seen today as an interesting alternative to conventional systems [26–28].

In this respect, the removal efficiency of *Panicum maximum* was identified to treat industrial effluents containing chemicals such as phenols, chlorophenols and heavy metals or wastewater from dairy industries and slaughterhouses [29–31]. Similarly, [32], studied three parallel constructed wetlands with free water surface (surface area of 1300 m^2 each) planted with torpedo grass (*Panicum hemitomon*) in Mississippi, USA, for tertiary treatment of bleach kraft pulp mill effluent. The removal efficiency was moderate for NO_3–N (80% in 1989, 64% in 1990), variable for (suspended solids) SS (81% and 33%) and TP (total phosphorus) (53% and 32%), low for NH_4–N (25% and 18%) and very low for BOD_5 (7 and 6%). In 1999, a constructed wetland with horizontal sub-surface flow was put in operation in Shushufindi, Ecuador, to treat wastewater from a slaughter house [33]. The system consists of a settling tank and two beds in series with a total surface area of 1200 m^2, planted with local plants *Echinochloa polystachia* (Carib grass) and *Panicum maximum*. The treatment performance of the system for the period June 1999–January 2000 was excellent. *Eichhornia crassipes* was used to purify wastewater which causes eutrophication [34,35] described the use of a hybrid constructed wetland for treatment of mixed industrial wastewaters at Yantian Industry Area in Baoan District, Shengzhen City, China. The system consisted of three parallel Water hyacinth (*Eichhornia crassipes*) wetlands (total surface area 825 m^2) followed by two constructed wetlands with horizontal subsurface flow (total area 1610 m^2) planted with *Phragmite australis*. At a hydraulic loading rate of 36.5 cm/d the average inflow COD, BOD_5, SS, (total nitrogen) TN and TP (total Phosphorus) concentrations of 456 mg/l; 189 mg/l; 232 mg/l; 22.3 mg/l and 4.7 mg/l were reduced to 88 mg/l; 59 mg/l; 3.2 mg/l; 15.5 mg/l and 1.8 mg/l; respectively.

In Cameroon, works on the treatment of wastewater and its impact on the environment were carried out by [36–41,17].

The purpose of our work is to study the physicochemical characterization of raw effluents from 11 food processing

Table 1
Food processing industries and cities where they are located.

Food processing industry	Type of sector	City of location	Geographical indications
SOSUCAM 1	Sugar refinery	Nkoteng	N:0 4.28331° E:012.06019°
CAMLAIT	Dairy	Douala	N:04.02292° E:009.43265°
S.C.R. Maya & CIE	Oil Mill/Soap Factory	Douala	N:04.09846° E:009.63154°
AZUR	Oil Mill/Soap factory	Douala	N:03.58556° E:009.48455°
GUINNESS	Brewery	Douala	N:04.05057° E:009.74431°
FERMENCAM	Distillery	Douala	N:04.06451° E:009.37180°
SOFAVINC	Winery	Yaoundé	N:03.81464° E:011.51001°
FERME Henri & Frères	Livestock	Yaoundé	N:03.84495° E:011.45468°
OK FOOD	Biscuit factory	Douala	N:04.04055° E:009.41047°
CHOCOCAM	Confectionery making	Douala	N:04.02106° E:009.43520°
SOSUCAM 2	Sugar refinery	Mbanjock	N:04.44383° E:011.90853°

sectors in Cameroon and the assessment of the capacity of *Eichhornia crassipes* and *Panicum maximum* to reduce pollutant loads of the effluents from a distillery (Fermencam).

2. Materials and methods

2.1. Study sites

Table 1 shows the different sectors of the studied food processing industries and the cities where they are locatedin Cameroon.

2.2. Sampling

In this study, 990 wastewater samples were collected from 11 food processing industries at the rate of one sample per month for 3 months. Each sampling campaign corresponded to the total of 30 wastewater samples collected between 8a.m and 4p.m during the manufacturing process. Thereafter, composite samples were collected prior to transport to the laboratory. These samples were stored in previously labeled polyethylene plastic bottles of 1 liter and transported to the laboratory in an insulated cooler where they were analyzed according to methodological requirements [42–44].

2.3. Physicochemical parameters analyzed in food processing effluents

The pH and temperature (T°) were measured in situ using a HQ11d Hach pH-meter. The Electrical Conductivity (EC), Total dissolved solids (TDS) and Salinity were measured in situ using a HQ14d Hach conductimeter.

The Chemical Oxygen Demand (COD) was quantified with the close-reflux dichromate reduction method at 150 °C for 2 h followed by a spectrophotometric quantification with a DR 3900 Hach spectrophotometer model Hach.

The Biochemical Oxygen Demand (BOD_5) was quantified after five days of incubation at 20 °C with Oxytop head gas sensors following inhibition of nitrification.

Ammonium (NH_4^-) was quantified with Nessler method and nitrate (NO_3^-) with the cadmium reduction (NitraVer 5 nitrate) method for extraction and quantified with Hach spectrophotometer DR 3900, nitrite (NO_2^-) by the NitriVer 3 Nitrite diazotization method using; the determination of phosphorus (PO_4^{3-}) was done by the molybdovanadate method and suspended solid (SS) was determined using photometric method and all the reading are recorded on a DR 3900 Hach spectrophotometer and values are expressed in mg/l.

Total Kjeldahl Nitrogen (NTK) was quantified through wet acid digestion followed by distillation in VELP SCIENTIFICA distiller and back titration with H_2SO_4 0,1N (AOAC, 1980). The color expressed in platinum/cobalt was determined by wavelength through direct spectrophotometric readings.

The heavy metals such as lead (Pb) and cadmium (Cd) were analyzed using Atomic Absorption Spectrophotometer [45]. Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) were determined through a spectrophotometric assay using a Perkin-Elmer flame spectrophotometer.

The assay of biological components in *Eichhornia crassipes* and *Panicum maximum* leaves involved the assay of chlorophyll using the method of Mac Kinney [46] and the determination of proteins, lipids, carbohydrates involved the calculation of the water and nitrogen content by the method of Kjeldahl, [47,48].

2.4. Experimental device

This device was planted behind the distillery and fermentation plant of Cameroon (Fermencam). Indeed, it is the molasses collected from the Sugar Company of Cameroon (Sosucam) which is the raw material for this food processing industry and effluent produced are called stillage.

The site is located in a 120m × 100m swampy area at Boadibo in the northwest of Douala with latitude 4°06′45.1″N and longitude 9°37′18.0″E. *Panicum maximum* seedlings were collected in the botanical garden of the University of Douala (50 feet), taken to the laboratory and introduced in a 40 l and 80 cm-deep recipient containing stillage effluent. *Eichhornia crassipes* were collected at the Bania bridge (tributary of Wouri), transported to the laboratory and introduced in another 40 l recipient containing stillage. In addition, *Panicum maximum* seedlings introduced into the sewerage system in polluted environment (behind Fermencam) are collected in an unpolluted environment of the study site and *Eichhornia crassipes* is taken from a tributary of the Wouri and introduced into the experimental device installed in a polluted environment (Fig. 1).

To see the removal rate, the sampling and analysis of water were done in the following order: – Sampling of stillage effluent released from the plant (at the sewer pipe);

– Sampling of the effluent following 5 days of treatment with *Panicum maximum* and *Eichhornia crassipes* in laboratory treatment devices;

– Sampling of the effluent following 4 weeks of treatment with *Panicum maximum* and *Eichhornia crassipes* in laboratory treatment devices and in treatment devices planted behind Fermencam.

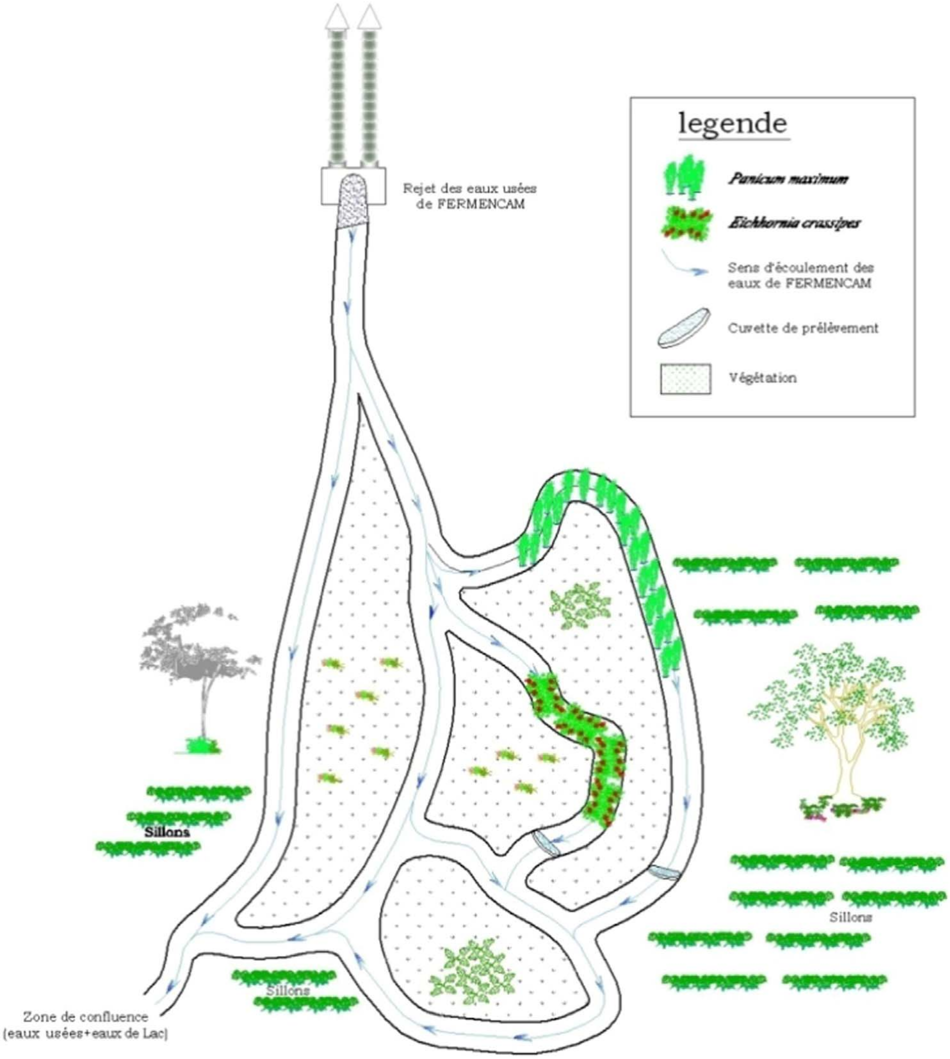

Fig. 1. Experimental device planted in polluted environment (behind Fermencam). To see the removal rate, the sampling and analysis of water were done in the following order.

2.5. Data analyses

Mean and standard deviation of the raw data was calculated by using XLSTAT 15.2 version; Pearson correlations were used to measure the degree of associations among the physicochemical variables. Relationships were considered significant when $p < 0.05$. Principal components analyses (PCA) were used to summarize relationships between physicochemical variables inside industries and within industries.

3. Results and discussion

3.1. Characterization of food industrial effluents

The results of physical and chemical parameters measured in 11 effluents discharged from food processing industries are shown in (Table 2). The pH values range from 4.07 to 7.63. Only oil mill effluent from the company Azur has a pH of 7.63; while the remaining effluent has an acidic pH. For oil mill effluent, the average value of 6.56 was found by [49], while [50] found a pH ranging from 7.43 to 9.56, and Verla et al. [51] found a pH of 4.67. In Camlait, the pH value is 4.53; these acidic pH values for dairy effluent correspond to values obtained by [52,53]. However, Wael and Mane [3] found a pH of 7.10; [54], a pH of 8.8 and [55], a pH ranging from 4.7 to 11. We can therefore conclude that the pH of dairy wastewaters depends on the nature of end product and can range from 6.6 to 12.2 [56,57]. Dairy wastes are largely neutral or slightly alkaline and have a

Table 2
Mean value and standard deviation of the physical and chemical parameters measured in effluent from agrifood industries.

Parameters	**Camlait**	**Sosucam 1**	**Ferme H et F**	**Sofavinc**	**Guinness**	**Sosucam 2**	**Azur**	**Okfood**	**Fermencam**	**S.C.R. maya**	**Chococam**
NH_4^+ (mg/l)	5.23 ± 5.26	104.98 ± 127.22	2925 ± 4049.69	1.80 ± 2.22	41.67 ± 45.11	177.3 ± 184.16	1.59 ± 0.90	3.702 ± 2.364	180.71 ± 60.33	1.23 ± 0.52	4.75 ± 3.18
NO_3^- (mg/l)	25.67 ± 13.68	127.43 ± 111.28	2629 ± 2763.54	5.60 ± 2.80	0.106 ± 0.024	1477.5 ± 1232.65	17.53 ± 11.60	26.400 ± 5.821	606.30 ± 89.42	6.83 ± 2.51	11.93 ± 6.35
NO_2^- (mg/l)	0.35 ± 0.13	0.45 ± 0.17	13.23 ± 6.35	0.031 ± 0.028	70.25 ± 24.99	2.79 ± 1.536	1.78 ± 0.79	0.293 ± 0.290	3.36 ± 2.67	0.094 ± 0.092	0.062 ± 0.082
COD (mg/l)	1007.3 ± 224.19	11333 ± 9715.45	10906.3 ± 10827.92	457.67 ± 362.61	1118 ± 73.369	357725 ± 386148.64	538 ± 665.41	1126 ± 27.94	26907.33 ± 36503.8	434.3 ± 203.23	2066 ± 1929.72
BOD_5 (mg/l)	170 ± 121.24	1164.33 ± 176.03	4066.67 ± 642.91	40 ± 10	337.67 ± 69.96	14491 ± 665.164	20.33 ± 6.028	168.37 ± 107.46	25044.67 ± 7432.56	44.3 ± 32.036	88 ± 29.87
NTK (mg/l)	16.31 ± 0.58	0.662 ± 0.40	275.64 ± 10.76	0.0 ± 0.0	0.212 ± 0.003	27.07 ± 0.86	88.39 ± 0.60	0.987 ± 0.138	13.45 ± 2.37	6.70 ± 0.60	1.19 ± 0,14
Ca^{2+} (mg/l)	16.48 ± 4.01	27.75 ± 6.70	38.898 ± 1.63	8.09 ± 1.516	1.27 ± 0.72	304.77 ± 23.78	0.303 ± 0.18	17.308 ± 1.97	296.82 ± 15.47	17.87 ± 3.53	22.93 ± 1.19
Mg^{2+} (mg/l)	5.73 ± 0.16	7.73 ± 1.41	9.51 ± 0.73	3.369 ± 0.784	2,70 ± 0,168	68,75 ± 10,31	0,883 ± 0,12	9,719 ± 0,301	72,67 ± 1,06	4,90 ± 0,30	2,15 ± 0,19
Na^+ (mg/l)	28.58 ± 4.91	5.592 ± 1.71	223.14 ± 23.62	1.960 ± 1.952	138.87 ± 13.69	1.29 ± 1.40	41.07 ± 64.92	5.644 ± 0.925	21.56 ± 0.98	21.43 ± 4.56	15.27 ± 5.90
K^+ (mg/l)	20.7 ± 1.08	41.838 ± 11.18	1841.85 ± 985.11	2.795 ± 1.902	24.71 ± 3.095	709.65 ± 211.98	18.30 ± 28.35	9.372 ± 0.850	849.51 ± 123.97	8.18 ± 0.76	5.40 ± 0.85
Cd^+ (mg/l)	0.097 ± 0.06	0.054 ± 0.072	0.158 ± 0.13	0.065 ± 0.086	0.134 ± 0.060	0.058 ± 0.096	0.097 ± 0.060	0.102 ± 0.004	0.078 ± 0.072	0.052 ± 0.05	0.10 ± 0.14
Pb^+ (mg/l)	0.24 ± 0.18	0.867 ± 0.472	0.658 ± 0.78	1.025 ± 0.588	0.283 ± 0.491	0.94 ± 1.63	0.250 ± 0.263	0.458 ± 0.402	0.32 ± 0.55	0.46 ± 0.67	0.083 ± 0.12
pH (mg/l)	4.53 ± 0.67	4.777 ± 0.13	5.67 ± 0.13	5.927 ± 0.526	5.663 ± 0.456	4.94 ± 0.24	7.63 ± 0.15	4.140 ± 0.234	4.07 ± 0.10	6.3 ± 0.40	5.37 ± 0.31
TDS (mg/l)	1091 ± 12.16	339.333 ± 84.58	20.43 ± 1.48	1215 ± 101.336	1486.3 ± 383.71	497.67 ± 56.72	1373.67 ± 246.03	1065.67 ± 55.54	495.67 ± 37.90	387.3 ± 63.89	537 ± 282.79
EC (μS)	1091.67 ± 11.85	338.667 ± 85.16	20.40 ± 1.60	1216 ± 99.955	1487.3 ± 381.83	497.33 ± 56.98	1407.67 ± 276.34	1068.33 ± 57.83	362 ± 23.43	386.67 ± 64.47	537.33 ± 283
Salinity (‰)	0.20 ± 0.0	0.033 ± 0.058	12.43 ± 1.16	0.033 ± 0.015	0.87 ± 0.231	2.57 ± 0.50	0.73 ± 0.058	0.10 ± 0.0	1.93 ± 0.12	0.10 ± 0.0	0.20 ± 0.17
Color (Pt/co)	1950.3 ± 608.62	1779 ± 438.83	79860 ± 34202.53	129 ± 8.660	1670 ± 995.857	32540 ± 5502.65	601.67 ± 104.04	1558 ± 245.126	21240 ± 2409.13	457.67 ± 215.33	1089.67 ± 874.6
SS (mg/l)	299.67 ± 89.97	300.667 ± 69.41	10793.33 ± 4442.09	16 ± 2.646	172.667 ± 135.3	2533 ± 540.03	78.67 ± 20.74	230.33 ± 44.970	1293.3 ± 156.95	44 ± 30.61	193.3 ± 228.27
PO_4^{3-} (mg/l)	46.97 ± 33.59	54 ± 22.15	3240 ± 328.19	3.567 ± 0.306	60.133 ± 50.343	1425.03 ± 83.01	17.87 ± 4.08	53.90 ± 11.523	1060.83 ± 197.99	10.57 ± 2.5	29.03 ± 28.58
T°	32.3 ± 1.53	31 ± 1	25.33 ± 0.58	28 ± 1	32 ± 2	41.67 ± 1.53	29.67 ± 1.53	33.667 ± 2.082	63.67 ± 7,095	30 ± 3	29 ± 1

Table 3
Pearson correlation matrix of the pH parameter measured in effluent from agrifood industries.

Variables	Guin ness	Sosu cam2	Sofa vinc	Ferme H &f	Sosu cam 1	Azur	Fermen cam	Scr maya	Choco cam	Cam lait	Ok food
Guinness	**1**	0.997	0.550	0.925	−0.106	−0.975	−0.530	0.506	0.136	0.672	−0.629
Sosucam 2	0.997	**1**	0.481	0.952	−0.185	−0.989	−0.461	0.573	0.215	0.729	−0.690
Sofavinc	0.550	0.481	**1**	0.190	0.772	−0.349	−**1.000**	−0.443	−0.753	−0.249	0.303
Ferme h&f	0.925	0.952	0.190	**1**	−0.477	−0.986	−0.167	0.796	0.503	0.904	−0.878
Sosucam 1	−0.106	−0.185	0.772	−0.477	**1**	0.326	−0.787	−0.912	−**1.000**	−0.807	0.839
Azur	−0.975	−0.989	−0.349	−0.986	0.326	**1**	0.327	−0.686	−0.354	−0.821	0.787
Fermencam	−0.530	−0.461	−**1.000**	−0.167	−0.787	0.327	**1**	0.463	0.768	0.271	−0.325
Scr maya	0.506	0.573	−0.443	0.796	−0.912	−0.686	0.463	**1**	0.923	0.979	−0.989
Chococam	0.136	0.215	−0.753	0.503	−**1.000**	−0.354	0.768	0.923	**1**	0.825	−0.855
Camlait	0.672	0.729	−0.249	0.904	−0.807	−0.821	0.271	0.979	0.825	**1**	−**0.998**
Okfood	−0.629	−0.690	0.303	−0.878	0.839	0.787	−0.325	−0.989	−0.855	−**0.998**	**1**

tendency to become acidic quite rapidly, because of the fermentation of milk sugar to lactic acid. The lower pH may lead to the precipitation of casein. Dairy wastes are characterized by strong butyric acid odor and heavy black flocculated sludge masses [58]. Dairy and related food industrial processing effluents are generated in an intermittent way and the flow rates of these effluents change significantly [59]. The types and size of processes and equipment used are determined by raw material inputs and the finished products manufactured. The effluent indicating acidic conditions could have an adverse effect on soil and microflora [60]. The alcohol fermentation industry is divided into three main categories: brewing, distilling and wine manufacture. Each of these categories produces waste waters with common characteristics such as low pH values and high concentrations of organics [61]. The brewery effluents like those of Guinness have usually very low pH, between 3 and 4 [62–66]. Correlation testing was carried out between the physical and chemical parameters measured in the effluents of each food processing industry. Thus, at Camlait the pH is positively correlated with the NTK, and has a significant p-value of 0.017; at Chococam the pH is negatively correlated with Ca^{2+} and has a very significant p-value of 0.005; even at the Ferme H&F pH is negatively correlated with salinity for a significant p-value of 0.023; all at a significance treshold of $\alpha = 0.05$.

The correlation of pH values carried out across all industries (Table 3) shows that Fermencam's pH is negatively correlated with Sofavinc's pH ($p = 0.015$), Okfood's pH is negatively correlated with Camlait's pH ($p = 0.036$); similarly, Sosucam1's pH is negatively correlated with Chococam's pH ($p = 0.019$) all at a significance threshold of $\alpha = 0.05$.

As a general rule, acidic pHs are found in effluent from food processing industries due to manufacturing processes [67,68,15]. However, these values do not meet wastewater discharge standards set by Government of Cameroon [69,70], pH between 6 and 9. Total dissolved salts (TDS), electrical conductivity (EC) and salinity show several correlations between them within an industry and among industries. Thus, there is an insignificant positive correlation between TDS and EC measured at Azur and Sosucam2; similarly, there is an insignificant positive correlation between TDS and EC measured at Camlait and Azur.

There is an insignificant positive correlation between the EC measured at Fermencam and Azur; a negative correlation between SCR maya and Azur, a negative and highly significant correlation between Fermencam and SCR maya ($p = 0.006$) with a level of $\alpha = 0.05$. For salinity, there is a negative and highly significant correlation ($p = 0.00001$) between Guinness and Sosucam1, and between Guinness and Azur. At Ferme H&F, there is a negative and insignificant correlation with Sofavin. There is a positive and very significant correlation between Sosucam 1 and Azur ($p = 0.00001$).

The conductivity measurement provides a good assessment of the degree of water mineralization whereby each ion acts by its concentration and specific conductivity. The recorded average values show significant variations. Similarly, the electrical conductivity and salinity serve as good indicators to assess dissolved matter [71,42]. They are strongly linked to other physico-chemical parameters. In this study they vary according to each effluent. Electric conductivity values recorded range from 20.40 μS/cm to 1487 μS/cm. Conductivity and total dissolved salts are high in effluents from Camlait (1091 μS/cm), Azur (1407 μS/cm) and Guinness (1497 μS/cm). For distillery effluents, [72] found conductivity values of 5100 μS/cm and 4700 μS/cm respectively in the stillage; this is inconsistent with values recorded at Fermencam (362 μS/cm). However, all the values observed are within the range of acceptable values recommended by the FAO which are 0–3000 μS/cm, and the WHO [70].

These results demonstrate strong mineralization mainly due to the organic load. In addition, all effluents show very low salinity values. The highest salinity value is found in the wastewaters of the Ferme H&F (12.43‰); the rest of the effluent varies from 0.033‰ to 2.57‰.

Effluent from Sosucam 2 show significant positive correlations in Fig. 2. However salinity is not correlated with any parameters. In effluent from Guinness, salinity is negatively correlated and insignificant with NH_4^+, it is also positively correlated with Ca^{2+} and very significant with Cd$^+$ ($p < 0.0001$). Effluent from Sofavinc show a conductivity positively correlated with TDS ($p = 0.021$), the salinity is not correlated with any parameters.

In effluent from Guinness, salinity is negatively correlated and insignificant with NH_4^+, it is also positively correlated with Ca^{2+} and very significant with Cd$^+$ ($p < 0.0001$). Effluent from Sofavinc show a conductivity positively correlated with TDS ($p = 0.021$), the salinity is not correlated with any parameters. In effluent from Ferme H&F (Fig.3A), TDS are negatively

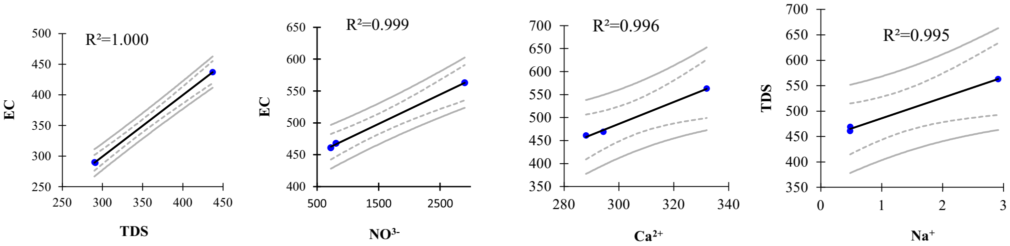

Fig. 2. Correlation lines between electrical conductivity (EC), total dissolved salts (TDS) and physico-chemical parameters measured in effluent from Sosucam2.

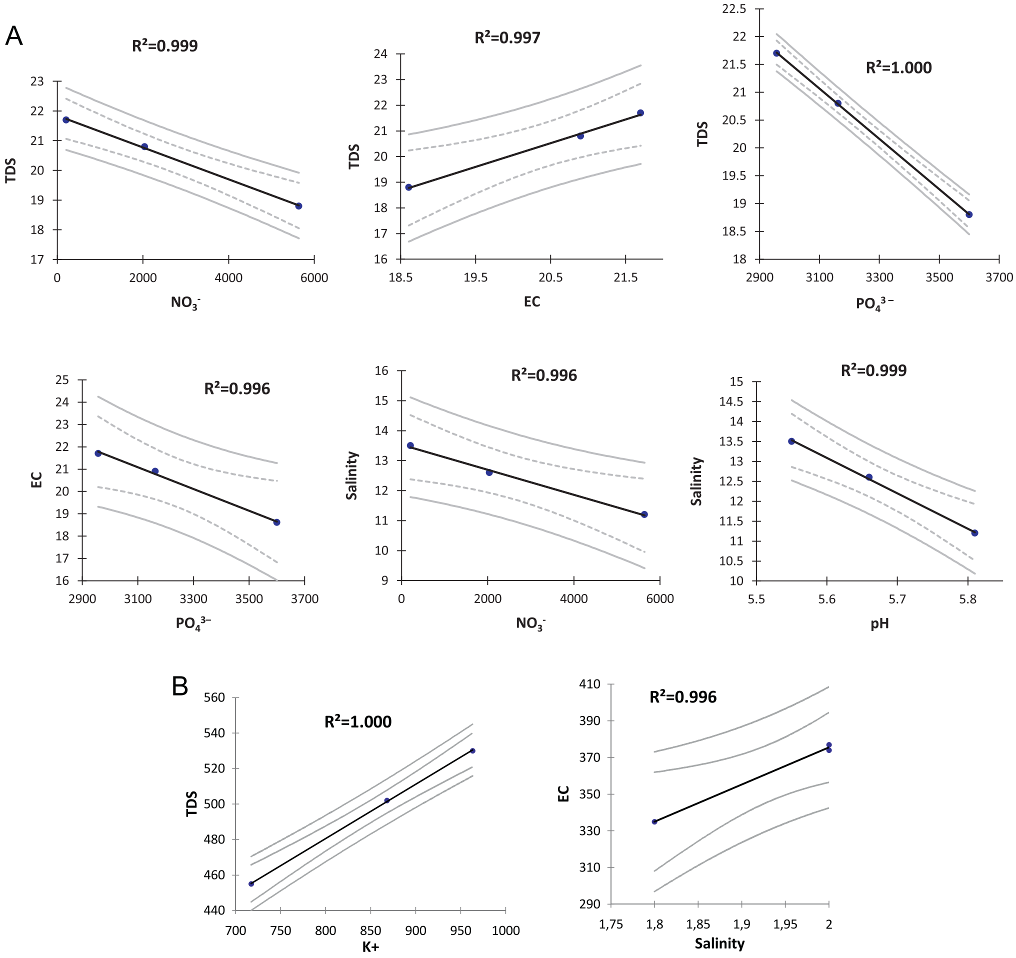

Fig. 3. (A) Correlation line of TDS, EC and salinity with other physico-chemical parameters measured in effluent from Ferme H&F; (B) Correlation line of the salinity and conductivity of effluent from Fermencam.

correlated with NO_3^-, positively correlated with conductivity, negatively correlated with PO_4^{3-} ($p=0.006$). Similarly the conductivity is negatively correlated with PO_4^-, salinity is negatively correlated with NO_3^- and pH ($p=0.039$).

Salinity of the effluents from the company Azur shows a negative correlation with NH_4^+, positive correlation with COD, Mg^+, Na^+ and highly significant correlation with K^+ ($p<0,0001$). Conductivity is positively correlated with NO_3^- and NTK. STDs are not correlated with any parameters. In stillage effluents from Fermencam DTDS are positively correlated with K^+ ($p=0.010$) and the conductivity is insignificantly correlated with salinity ($p=0.041$). In oil mill effluent from SCR maya, salinity is very low and is not correlated with any parameters, conductivity and total dissolved salts (TDS) are positively correlated respectively with COD and negatively with NTK. These two parameters are positively correlated with Pb^{2+}. STD are significantly correlated with the conductivity ($p<0.00001$). At Chococam, TDS are positively correlated with Pb^{2+}, as well as conductivity. There is a positive and very significant correlation between TDS and conductivity ($p=0.001$). Salinity is

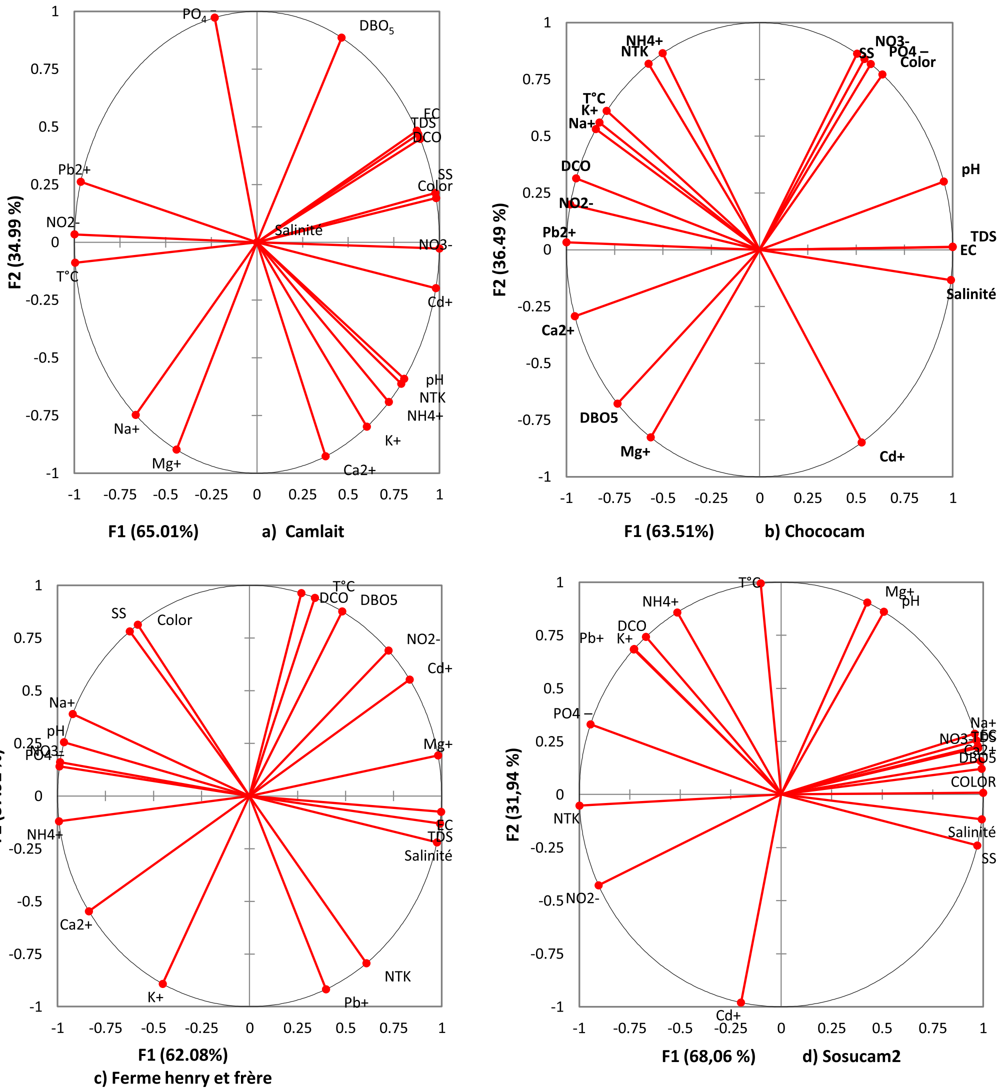

Fig. 4. Principal Component Analysis (PCA) found in each food processing industry. a) Camlait; b) Chococam; c) Sosucam 2; d) Ferme henry et frère.

negatively correlated with NO_2^- but insignificant ($p = 0.042$).

In the dairy effluents, salinity is correlated with no parameters. Conductivity and total dissolved salts (TDS) are respectively and positively correlated to the COD ($p=0.011$; $p= 0.014$). Conductivity and total dissolved salts are positively correlated ($p=0.026$). Effluents from Okfood show a correlation between TDS and NH_4^+ ($p=0.034$); EC and NH_4^+ ($p=0.003$); EC and TDS ($p=0.037$). Effluents from the sugar refinery Sosucam 1 show that the three STD, conductivity and salinity parameters are positively correlated to NH_4^+ and Mg^+. Salinity is positively correlated to TDS, as well as EC is positively correlated to TDS. P-values are below the threshold $\alpha = 0.05$ and therefore insignificant. The results of the electrical conductivity are different from those found by [73] who analyzed several effluents from the food processing industry in Nigeria, and from those of [74].

Fig. 4 shows the principal component analyses (PCA) carried out between physico-chemical parameters measured in each effluent collected from food processing industries. Firstly, these analyses highlight similarities or contrasts between these parameters. Secondly, they highlight elements that are mostly correlated elements. Interpretation of the results is limited to the first two factorial designs, and the Kaiser criterion was used to select the highest percentage of the total inertia. In these PCA, variables are represented by 20 physico-chemical parameters and individuals correspond to the different food processing industries mentioned.

Camlait's PCA shows that F1 contributes 65% and F2 34.99%. 13 variables contributed to the formation of the F1 axis. But variables that contribute most are the following: NO_3^-, NO_2^-˙ Color, SS, T°, Cd^+ and Pb^{2+}. Therefore, axis 1 opposes parameters contributing to dairy effluent enrichment with organic matter to exchangeable cations causing mineralization and well represented on axis 2 (Ca^{2+}˙ Mg^+, Na^+ and K^+).

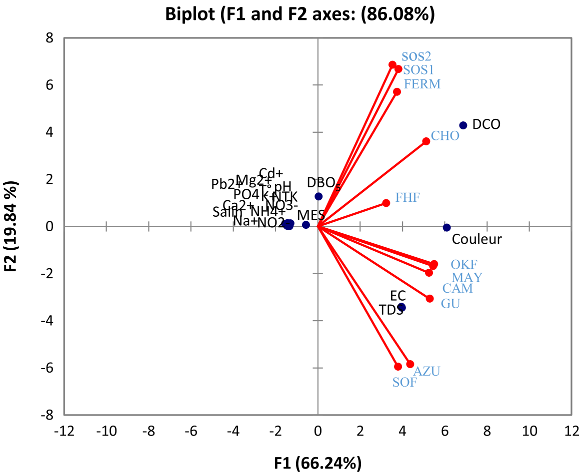

Fig. 5. Principal Component Analysis (PCA) observed among food processing industries. (CAM) Camlait; (CHO) Chococam; (MAY) S.C.R. Maya; (FERM) Fermencam; (AZU) Azur; (SOS 1) Sosucam 1; (FHF) Ferme henre&frère; (SOF) Sofavinc; (SOS 2) Sosucam 2; j) (GU) Guinness; k) (OKF) OKFood.

As concerns Chococam, salinity, EC, TDS, pH parameters strongly contribute to the formation of the axis F1 (63.51%). This reflects the weakness of these effluents in organic matter. Axis 1 opposes salinity, EC, TDS, pH parameters to Cd^+, Pb^+, Ca^{2+}‚ Mg^+, Na^+, K^+, COD, BOD_5, NO_2^-, T° parameters. Axis 2 (36.49%) is related to NH_4^+, NO_3^-, NTK, SS, color, PO_4^-.

As concerns Sosucam 2, F1 contributes 68.06% and F2 31.93%. Some significant negative correlations were observed between nitrites (NO_2^-) and nitrates (NO_3^-); between NO_2^- and BOD_5; between NTK and nitrates; between PO_4^- and NO_3^-; between NO_2^- and Na^+; between BOD_5 and NTK. F1 axis opposes F2 with parameters contributing to its formation, including: NO_2^-, BO_{D5}, NO_3^-, NTK, Ca^{2+}, Na^+, K^+, EC, TDS, SS, color, PO_4^{3-} and Pb^{2+}. This means that molasses found in Sosucam 2 is very rich in organic matter. Axis A2 is represented by: NH_4^+, COD, Cd^+, Mg^+, pH, T.

In livestock effluents represented here by Ferme H&F, PCA shows that the F1 axis is formed with the contribution of 12 variables and F2 axis with 8 variables. Negative and significant correlations were found between: Nitrate and NH_4^+; Mg^+ and NH_4^+; PO_4^{3-} and NH_4^+, salinity and NH_4^+; K^+ and COD; K^+ and BOD_5; color and NTK; TSS and NTK; Cd^+ and Ca^{2+}; Ca^{2+} and Mg^+. Positive correlations can also be found.

In general, PCA from other industries show a sound contribution of physico-chemical variables in the formation of the F1 and F2 axes, as well as similarities between parameters. Fig. 5 shows ACP of all industries studied and physico-chemical parameters measured in the effluent. These effluents can be grouped into four classes (Fig. 6).

A color unit (CU) is considered as equivalent to 1 mg of cobalt in the presence of platinum (Platinum-Cobalt Color Scale [Pt/Co] or Apha-Hazen Scale). From 15 CU, it is possible to perceive water coloring in a glass of water. The highest values are observed in Ferme H&F (with an average of 79860 ± 34202.53 Pt/Co), followed by Sosucam2 (32540 ± 5502.65 Pt/Co) and Fermencam (21240 ± 2409.13 Pt/Co). Lowest concentrations are found in Sofavinc, Azur, Camlait and Okfood with concentrations of 129 ± 8,660 Pt/Co; 601.67 ± 104.04 Pt/Co; 1950.3 ± 608.62 Pt/Co and 1558 ± 245.126 Pt/Co respectively. Manjushree et al. [75], found concentrations of 1760 Pt/Co in untreated tannery effluents, which are below some effluents we studied but which were 117 times higher than all the values recommended by standards. The color of the water is due to the presence of colored organic matter (humic substances), metals or industrial discharges. The color of the water is mainly

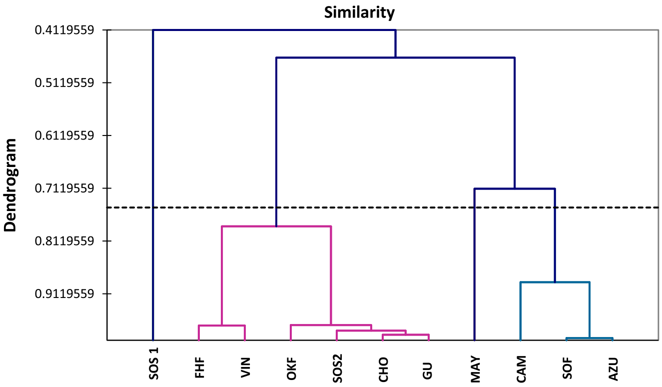

Fig. 6. Similarity dendrogram among food processing industries. (CAM) Camlait; (CHO) Chococam; (MAY) S.C.R. Maya; (FERM) Fermencam; (AZU) Azur; (SOS 1) Sosucam 1; (FHF) Ferme henry et frère; (SOF) Sofavinc; (SOS 2) Sosucam 2; j) (GU) Guinness; k) (OKF) OKFood.

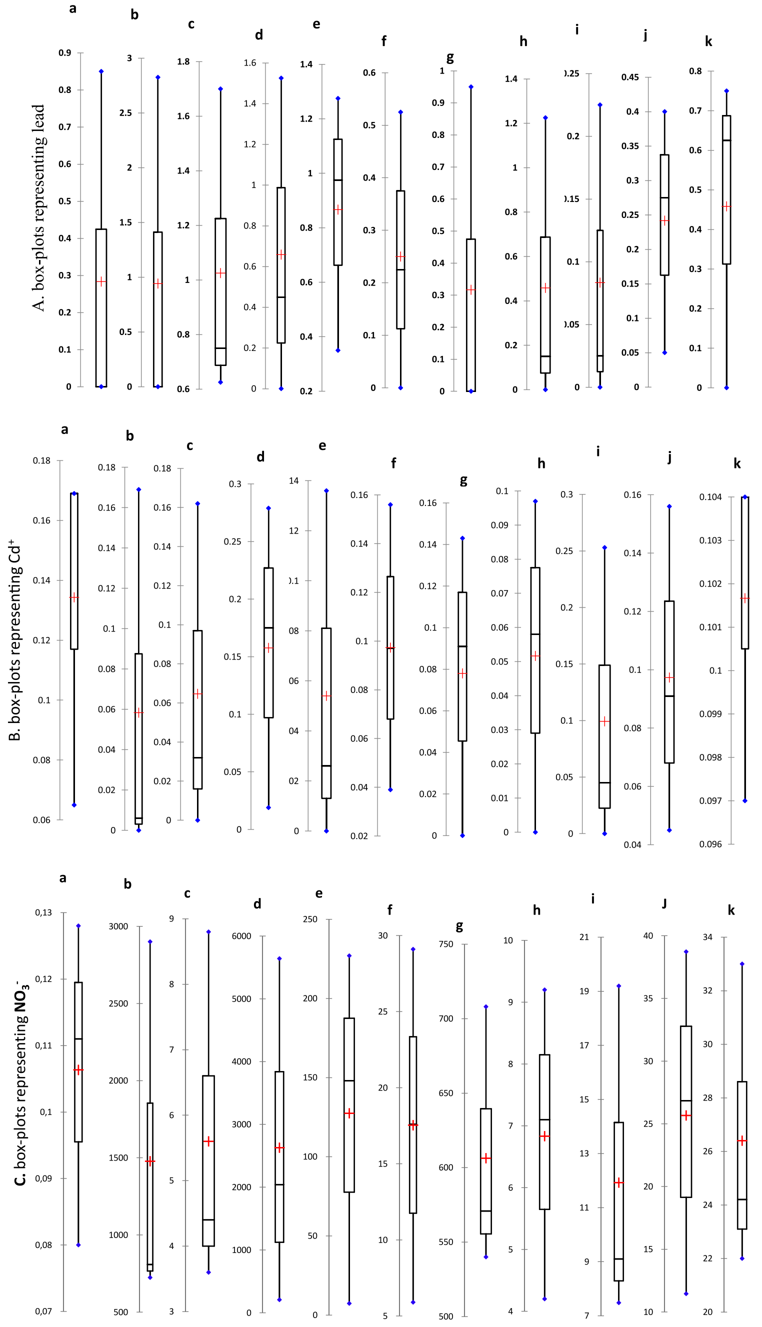

Fig. 7. a) Guinness; b) Sosucam 2; c) Sofavinc; d) Ferme Henry; e) Sosucam1; f) Azur; g) Fermencam; h) SCR Maya; i) Chococam; j) Camlait; k) Okfood. The box represents the 1st and 3rd percentiles; the black band the median; the whiskers are the minimum and maximum values. (A) is box-plots representing lead, (B) is box-plots representing Cd^+ and (C) is box-plots representing NO^{3-}.

caused by the presence of little or no settleable colloidal particles suspended. However, due to an abnormal concentration of certain elements in the water after any particular pollution, the color of the water changes and is currently influenced by the color of these pollutants. Correlations between the color and other physicochemical parameters may justify these large concentrations observed.

Fig. 7A and B shows that the lead (Pb^{2+}) and Cadmium (Cd^+) levels are low in all effluents; however, the largest lead concentration is found in the effluent from Sofavinc (1,025 mg/l), followed by Sosucam2 (0,94 mg/l) and Sosucam1 (0,86 mg/l). Cadmium (Cd^+) level ranges from 0.052 mg/l in effluents from SCR Maya to 0.158 mg/l in effluents from Ferme

H&F. These results are different from those obtained by [76], who found that lead value in Ice cream effluent was 0.65 mg/l while it was 0.29 mg/l in sweet-snack effluent; dairy effluent showed much lesser amount of lead content (0,040 mg/l). For cadmium, they found high values in all three effluents with values ranging from 0,45 mg/l (dairy); 0.91 mg/l (sweet snack) and 0.87 mg/l in Ice cream effluent. Heavy metals and other toxicants enter in soil which is irrigated with polluted waters and show toxic effects on plants and animals [77]. Trace element and other heavy metals also enter in dairy effluents through therapeutic compounds and organic materials from pesticides [78,35].

Various forms of nitrogen were estimated through the measurement of the following: NH_4^+, NO_3^-, NO_2^-, and NTK. Nitrogen present in the waste water may be organic or inorganic in nature. Organic nitrogen is mainly a component of proteins, polypeptides, amino acids and urea. Mineral nitrogen, including ammonium (NH_4^+), nitrites (NO_2^-) and nitrates (NO_3^-), constitutes the major part of the total nitrogen. Ammonium or ammoniacal nitrogen ranges from 1.23 mg/l in SCR Maya to 2925 mg/l in the effluent of Ferme H & F. These results are contrary to those found by [79]. in the effluents from the slaughterhouse with 163.7 mg/l of NH_4^+. The large concentrations of ammonium may be due to the mineralization of organic nitrogen in effluents [80,81].

Nitrates levels are high in Ferme H & F (2629 mg/l), in Sosucam2 (1477.5 mg/l) and Fermencam (606.30 mg/l) (Fig. 7**C**). Nitrate levels in the effluent from the Kenitra slaughterhouse range from 0.349 mg/l to 4.125 mg/l, with an average concentration of 1.742 mg/l [82]. The increase in the nitrate and ammonium contents may be caused by the richness of effluents in organic matter due to the plant and animal origin of food processing effluents. Concerning nitrites, which are an important step in the metabolism of nitrogen compounds, they also make their way into the nitrogen cycle between ammonium and nitrates. Nitrites generally derive either from an incomplete degradation of ammonia or a nitrate reduction, and they represent only one intermediate stage and are easily oxidized to nitrate (chemically or bacterially). Nitrite levels range from 0.031 mg/l to 70.25 mg/l. Nitrite levels of 13.23 mg/l and 70.25 mg/l in the effluents from Ferme H & F and Guinness respectively. The low levels of nitrites found in wastewater studied could be explained by the fact that nitrite ion (NO_2^-) is an intermediate compound which is unstable in the presence of oxygen and whose level is typically much lower than that the two forms related to it, that is nitrates and ammonium ions [83]. Kjeldahl Nitrogen (TKN), which includes organic nitrogen and ammonium, is high in Ferme H & F (275.63 mg/l), as well as in Fermencam and Azur. Such higher concentrations of nitrogen compounds may contribute significantly to the eutrophication of receiving waters [84].

Phosphorus compounds exist in wastewater in different forms, namely soluble orthophosphate, water-soluble phosphates and organophosphorus derivatives. Orthophosphate levels recorded were very high in effluents from Ferme H & F (3240 mg/l), Sosucam (1425 mg/l) and Fermencam (1060 mg/l). Chennaoui et al. [85] reported an average content of orthophosphate of 1.8 g/l in the slaughterhouse wastewater in Canada, while Massé and Masse [86] reported values ranging between 25 and 42 mg/l. However 20–50 mg/l of nitrates and 0–20 mg/l of phosphates are permissible for irrigation [70]. More than 65% of the samples are having higher concentration levels; they are unfit for irrigation without proper treatments. The presence of nitrates in dairy wastewater may be attributed to milk containing. Phosphate mainly contributed through detergents and soaps widely used for cleaning purposes in processing unit [87].

If the COD value is much bigger than the BOD value, the organic compounds in wastewater are slowly biodegradable [88,87]. This ratio is very high in Azur's oil mill effluents (26.45); followed by molasses effluent collected in Sosucam2 (24.68); then Chococam (23.48); Sosucam 1 (9.73); SCR Maya (9.79); Okfood (6.68); Camlait (3.31); Ferme H&F (2.68) and the lowest value is found in the stillage effluent of Fermencam (1.07). COD average values range from 434.3 mg/l in oil mill effluents to 357725 mg/l in molasses effluent from Sosucam 2. This high level of COD was found by [89] in stillage effluents (104000–134400 mg/l), while [84]; found in effluent from fish processing industries a COD of 1825 mg/l; [49] a COD of 1806.33 mg/l respectively in palm oil refinery effluents. Significant variations in COD (80–95000 mg/l) and BOD (40–48000 mg/l) have been reported by various investigators of dairy wastewater [25]. Dairy wastewater has high concentration of dissolved organic components like whey proteins, lactose, fat and minerals [90,91] and it is also malodorous because of the decomposition of some of the contaminants causing discomfort to the surrounding population. As a result, all effluents studied are very rich in less biodegradable organic matter and all values are above the limit allowed by WHO [92,70]. These high values of COD and BOD_5 can be explained by the richness of effluents in different forms of nitrogen such as ammonium (NH_4^+); nitrate (NH_3^+) and Kjeldal nitrogen (NTK) from mineralization of organic matter. The high level of suspended matter of these effluents also reflects this rich organic matter, thereby increasing effluent COD concentration [93]. Distillery wastewaters like Fermencam are characterized by high concentrations of BOD_5, COD, phenolic compounds and low pH. Distillery spent wash (also called stillage) is the residual liquid waste generated during alcohol production and represents a serious threat to water bodies due to high organic load, dark brown color and unpleasant odor [94–97]. The stillage yield with respect to the volume of ethanol produced from sugarcane is in the range of 10–15 L of stillage per liter of ethanol produced [98–100].

The beet sugar factory wastewater like Sosucam1 usually have high concentrations of organics [101,102]. Molasses wastewater like Sosucam2 usually contains high concentrations of nitrogen, phosphorus and potassium and it is dark brown in color [103,64]. The brewery effluents like those of Guinness contain high concentrations of organics arising from dissolved carbohydrates, the alcohol from beer wastes, and high concentrations of suspended solids such as spent maize, malt, and yeast [62,104,63].

Oil mill effluents such as olive oil are often acidic and usually contain very high concentrations of organics and suspended solids together with high concentrations of phenols, oils and grease and fatty acids [19–22] . These results can also be observed in Azur and SCR Maya.

Table 4
Results of chlorophyll determination in *Panicum maximum* and *Eichhornia crassipes* leaves.

Species	Environment	Chlorophyll a	Chlorophyll b	Chlorophyll a+b	P
Panicum maximum	Polluted environment	17.39 ± 0.84	31.57 ± 0.63	48.96 ± 1.46	0.234
	Non polluted environment of the site	17.14 ± 0.78	30.93 ± 1.86	48.07 ± 2.60	
Eichhornia crassipes	Polluted environment	17.91 ± 0.73	31.26 ± 0.91	49.18 ± 1.41	0.032 (*)
	Non polluted environment of the site	17.04 ± 0.12	30.60 ± 0.37	47.64 ± 0.48	

Compared with the effluent from Ferme H&F, slaughterhouse effluents produce large volumes of wastewater which usually contains high concentrations of biodegradable organic matter in soluble fraction as well as in insoluble fraction in the form of colloidal and suspended matter such as fats, proteins and cellulose [105] . It contains high concentrations of oil and grease up to 1000 mg/l [106,105]. In addition, abattoir wastewaters carry high levels of pathogenic microorganisms that may constitute a risk for humans and animals [105].

The values of suspended solids (SS) range from 16 mg/l in effluents from Sofavinc to 10793.33 mg/l in effluents from Ferme H & F. In dairy effluents from Camlait SS values of 299.67 mg/l have been reported. The concentration of suspended solids varies in the range of 0.024–4.5 g/l significant amount of nutrients, 14–830 mg/l of total nitrogen and 9–280 mg/l of total phosphorus are also found in dairy wastewater [55,107,108] . They may be alkaline or acidic, and very often contain additives like phosphates, sequestering agents, surfactants [109]. Significant amount of Na, Cl, K, Ca, Mg, Fe, CO, Ni, Mn are also always present in dairy wastewater. In effluents from Camlait, values of 16.48 mg/l; 5.73 mg/l; 28.58 mg/l and 20.7 mg/l were found respectively for Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} concentrations. The presence of high concentration of Na^{+} is due to the use of large amount of alkaline cleaners in dairy plant [23,91,110–112]. In all effluents, Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} ion concentrations are higher in Sosucam 2, Fermencam and Ferme H&F.

3.2. Stillage treatment trial in Fermenterie du Cameroun (Fermencam)

Table 4 shows the results of chlorophyll determination in *Panicum maximum* and *Eichhornia crassipes* leaves. The chlorophyll content (a + b) of *Eichhornia crassipes* leaves (49.18 ± 1.41) in a polluted environment is significantly higher than the sampling of *Eichhornia crassipes* leaves (47,64 ± 0,48) in an unpolluted environment, for a 95% confidence interval Table 5 shows the levels of proteins, fats and carbohydrates in % of dry matter in *Eichhornia crassipes* and *Panicum maximum* leaves.

Table 6 shows the concentrations of physico-chemical parameters of the wastewater sampled at the outlet of the plant. The values of physico-chemical parameters of the wastewater collected at the outlet of the plant are different. Conductivity, total dissolved salts (TDS), COD and BOD_5 were very high compared to the SS, phosphate, nitrate and cadmium.

Table 7 shows the purification performance of *Panicum maximum* and *Eichhornia crassipes* leaves after 5 days of treatment of wastewater in the laboratory basins. Concentrations of pH, conductivity and TDS decreased in comparison with the concentration of the parameters measured at the outlet of the plant.

The results obtained in Table 4 show that the synthesis of chlorophyll in *Eichhornia crassipes* and *Panicum maximum* leaves may be due to the quality of the environment, but also to the sensitivity of the species. In fact, according to [112], the chlorophyll (a + b) levels of *Commelina benghalensis* and *Alternantera sessilis* leaves in Fermencam are lower than those found in the same bodies of such species in a less polluted site. The analysis of these results shows that the polluted environment can influence the chlorophyll (a + b) levels, and this is the case of *Eichhornia crassipes* and *Panicum maximum*; their chlorophyll level is higher than in the non-polluted environment.

Regarding protein, fat and carbohydrates contents in leaves of both species in Table 5, the protein and fat contents of the polluted environment (behind Fermencam) are significantly lower than those of the non-polluted environment; in contrast, the carbohydrate contents are very high in the polluted environment. The decrease in the protein and fat levels in the polluted environment may be due to the metabolism of synthesis of these components which could lead to the production of carbohydrate for growth of the photosynthesis activity and the biomass production. Priso et al. [112] showed that in the polluted environment of Fermencam, *Zea mays, Eleusine indica* and *Commelina benghalensis* have significantly higher protein contents than those found in the natural environment; in addition, fat and carbohydrate contents are significantly higher in the natural environment than in the polluted environment.

Table 5
Levels of proteins, fats and carbohydrates in % of dry matter in *Eichhornia crassipes* and *Panicum maximum* leaves.

Species	Environment	Proteins	Ash	Fats	Carbohydrates
Panicum maximum	Polluted environment	6	6.6	5.8	81.6
	Non polluted environment of the site	14.5	7.3	8.9	69.30
Eichhornia crassipes	Polluted environment	6.2	3.2	7.5	83
	Non polluted environment of the site	17.5	5.7	10.8	66

Table 6
Levels of physico-chemical parameters of the wastewater collected at the outlet of the plant.

Parameters	Outlet of the plant
pH (pH unit)	4.5
Conductivity (μs/cm)	4700
Temperature (Degree Celsius)	36.5
TDS (mg/l)	3100
COD (mg of O2/l)	22500
BOD5 (mg of O2/l)	20300
TSS (mg/l)	100
Phosphate (mg/l)	101
Nitrates (mg/l)	12
Cadmium (μg/l)	422.9

Table 7
Purification performance of *Panicum maximum* and *Eichhornia crassipes* in experimental devices of Fermencam and the laboratory after 4 weeks of treatment.

Place of sampling	Sewer outlet of the plant	Behind Fermencam		laboratory of the Plant Biology	
Parameters	Wastewater before treatment	*Eichhornia crassipes*	*Panicum maximum*	*Eichhornia crassipes*	*Panicum maximum*
pH	4.5	6.55	6.54	6.45	7.5
Conductivity (μs/cm)	4700	352	672	4320	3895
Temperature (°C)	36.5	29	28	28.8	29
TDS (mg/l)	3100	351	576	2749	2348
COD (mg of O2/l)	22500	150	380	6900	3600
BOD_5 (mg of O2/l)	20300	123	239	5320	2940
SS (mg/l)	100	8	12	30	30
Phosphate (mg/l)	101	2.43	102	63	62
Nitrates (mg/l)	12	8	0	8.4	15
Cadmium (μg/l)	422.9	141.3	153.4	177.3	150.6

Concentrations of the physico-chemical parameters of the wastewater sampled at the output of the plant in Table 6 show a high temperature (36.5 °C); besides [112-113] reported a temperature of 52.8 °C in Fermencam. These high temperatures are due to hot production equipment rinsate, accelerating the acidification process by fermentation. High temperatures hamper aquatic life and many organisms without thermal control mechanisms will have their vital activities slowed [114,115]. The pH of Fermencam site is acidic, a pH of such magnitude is detrimental to the environment. The increase of conductivity and decrease of total dissolved salts are due to the excessive mineralization of organic matter [116]. According to [117], the conductivity of a solution helps to estimate the total dissolved salt contents. COD, which is an overall assessment of organic pollution, shows a higher value at the output of the plant. The organic matter contained in effluent at the output corresponds to sugar from losses at various points in the manufacturing process and to organic acids resulting from fermentation in the effluent pipe and storage areas. The oxidation of the COD generates carbon dioxide (CO_2) which acidifies the environment. High values of TSS can prevent light penetration, reduce dissolved oxygen, limiting the development of aquatic life and creating imbalances between the various species. SS levels influence water turbidity and color. Nitrate level is much lower than that obtained by Noukeu and Priso [72]; whereby pollution in fermenteries du Cameroun (Fermencam) was very high (65 mg/l). The high level of phosphate in the environment compared to that obtained in 2005 by Mbouano quoted by Noukeu and Priso [72] (66.08 mg/l) is due to frequent use of detergents, cleansing soap and phosphate-rich products. Heavy metals such as cadmium from water are necessary for normal development of the plants. They play an important role in the transformation of the material, mainly in enzymatic mechanisms; beyond the maximum threshold, they inhibit the growth and development and can even be toxic [118]. Their levels can be explained by the presence of high phosphate ion concentrations, the use of chemical compounds for maintenance or the acidity of the environment which may render these ions mobile.

Table 7 presents the purification performance concentration values of each sanitation system according to plants used. In comparison with the parameter values obtained at the output of the plant (equipment feed water), the laboratory equipment shows a significant decrease in the concentration of pollution loads in the basin containing *Eichhornia crassipes* and the *Panicum maximum*; the same goes for the device planted behind Fermencam. In the laboratory equipment, *Eichhornia crassipes* increases the pH of the feed water from 4.5 to 6.45 while *Panicum maximum* increases the pH of the feed water from 4.5 to 7.5. The electrical conductivity of the feed water is 4700 μS/cm, it drops to 3844 μS/cm and to 3895 μS/cm respectively in basins containing *Eichhornia crassipes* and *Panicum maximum.*

These observations continue into the experimental device installed in Fermencam. The pH value in both devices is due to lower nitrification activities in devices and to lower oxidation of COD. The decrease of the electrical conductivity may be due to salt retention in the filtrates. These salts may be retained by various physico-chemical and biochemical reactions (absorption, ion exchange, oxidation, neutralization). It should be noted that in the devices of the research site, the treatment efficiency of the conductivity is: 17% for *Panicum maximum* and 18.21% for *Eichhornia crassipes* in the laboratory while in Fermencam their respective values are: 85.7% and 92.5%. These electric conductivity results of devices planted with *Panicum maximum* are similar to those of [119] which is in the urban wastewater, a concentration of 1454.4 µS/cm and after treatment in the beds planted with *Panicum maximum,* value of 863 µS/cm. The concentrations of total dissolved salts (TDS) also declined in both devices. The treatment efficiency of other parameters with *Eichhornia crassipes* in the Fermencam device show the respective values: COD (99.33%); BOD_5 (99.39%); SS (92%); PO_4^{3-} (98.57%); NO_3^- (33.33%); cadmium (66.66%). In contrast, for *Panicum maximum* these values are respectively: 98.31%; 98.82%; 88%; 0.99%; 100%; 63.73% for the same above parameters. In the laboratory, the respective values are associated with *Panicum maximum* for parameters mentioned in the above order: 84%; 85.5%; 70%; 38.61%; −25%; 64%, while *Eichhornia crassipes* show the following values: 69.33%; 73.79%; 70%; 37.62%; 30%; 58.07%. Mandi (1992) reports an elimination of the organic load and suspended solids after treatment of industrial wastewater using *Eichhornia crassipes*; the results are a reduction of 78% for COD, and 90% for SS. Billore et al. [97], reported on the use of constructed wetlands with horizontal sub-surface flow to treat the secondary treated distillery effluent from a private distillery. The treatment system consisted of pretreatment chamber and four cell-constructed wetlands with horizontal sub-surface flow with total area of 364 m^2 planted with *Typha latifolia* and *Phragmites karka* in cells 3 and 4, respectively.

The BOD_5 and COD concentrations in the distillery effluent even after the conventional secondary treatment amounted to 2540 mg/l and 13.866 mg/l, respectively, and therefore, additional treatment was necessary. The system achieved COD, BOD_5, TKN and TP (Total Phosphorus) reductions of 64%, 84%, 59% and 79% respectively. The study indicated that constructed wetlands may be a suitable tertiary treatment option for distillery wastewaters. Olguín et al. [94] also reported on the use of experimental constructed wetlands with horizontal sub-surface flow for treatment of diluted sugarcane molasses stillage in Veracruz, México. The experimental units were filled with volcanic gravel and planted with *Pontederia sagittata*. Despite dilution, the inflow concentrations of organics were high and reached the average values of 1181 mg/l and 534 mg/l for COD and BOD_5, respectively. At the hydraulic retention time of 2.5 and 5 days, the respective inflow COD loadings amounted to 473 and 946 kg COD/ha/days. There was not much difference in treatment efficiency between the studied hydraulic retention times, with the exception of BOD_5 and NH_4^- for which the removal efficiency at hydraulic retention time of 5 days was superior to hydraulic retention time of 2.5 days. The experimental units were able to remove COD in the range of 80.2–80.6%, BOD_5 (82.2–87,1%), TKN (73.4–76.1%), NO_3^- (56–58.7%), NH_4^- (2–10%) and SO_4^{2-} (68.6–69.5%) depending on the hydraulic retention time. The authors pointed out that phosphorus and potassium were not removed but this fact may not matter as the effluent can be used for sugarcane field’s irrigation.

The decrease in the COD concentration is likely due to the physical retention of the organic matter of the wastewater in sewage systems and to the oxidation thereof by the microbial flora involved in the reduction in COD, bringing oxygen into the units via the roots and rhizomes [120-122]. In addition, plants contribute to the development of microbial biomass within surface organic deposits through the shade they provide and humidity they maintain.

The fact that the removal efficiency of COD and SS with hyacinth (*Eichhornia crassipes*) in the Fermencam unit is greater than that of the laboratory unit is due to the high density of biomass of hyacinth proliferating in the polluted environment while in the laboratory, Hyacinth's feet are renewed after 5 days because they begin to wilt and this can help to increase the amount of organic material in the vessel causing the production of hydrogen sulfide and unpleasant odors. According to [123]; harvesting and ventilation are effective ways to avoid these disadvantages. An important part of the purifying role of water hyacinth is the capture of suspended solids thus including a fraction of chemical pollution, according to two filtration-absorption processes through root system and sedimentation preventing horizontal movements of the suspended solids [124,125].

The BOD_5/COD ratio of the laboratory unit is 0.81 for *Panicum maximum* and 0.77 for *Eichhornia.crassipes.* In Fermencam's unit this unit is 0.82 for *Panicum maximum* and 0.63 for *Eichhornia crassipes*. These ratios show that the organic matter has been degraded by plants in comparison with the BOD_5/COD (0.90) ratio of water from Fermencam collected at the output of the plant. Pétémanagnan [119] reported a treatment efficiency of 91% for COD and 85.5% for SS, 74% for PO_4^{3-} in beds planted with *Panicum maximum*. The decrease in SS level in both units is due to the physical filtration which retains surface coarse and finer material, through pore blockage, capture and fixing on grains of sand or Van Der Walls-type of chemical interactions [126]. PO_4^{3-} concentration decreased, except in the site of the unit with *Panicum maximum*; this reduction may result from a bacterial and / or plant assimilation and by adsorption of PO_4^{3-} in the units [127,128]. In addition, the nature of the soil can positively influence the retention of PO_4^{3-} [129-131]. Unlike the laboratory device, Fermencam's device provides a better PO_4^{3-} removal performance that can be seen for hyacinth. This difference could be explained by the fact that *Eichhornia crassipes* probably need a PO_4^{3-} higher than *Panicum maximum.* The reduction in nitrate is due to both physico-chemical and biological removal mechanisms through nitrifying bacteria. Its increase is due to the nitrification of ammonium. In fact, the roots of the aquatic plants contribute to nitrobacterial adhesion and growth accounting in the decrease of ammoniacal nitrogen [132]. This symbiosis between nitrobacteria and roots makes these plants more interesting to use in the fight against eutrophication of aquatic environments. The removal of cadmium concentration is higher in *Eichhornia crassipes* with a removal efficiency of 66.66% in the experimental device and 58.07% in the laboratory device. Both results are different from those observed in *Panicum maximum*. Murphy et al. [133] reported on the use of 800 m^2 constructed wetlands with horizontal sub-surface flow planted with *Typha latifolia* to remove copper from a distillery effluent at a malt whisky distillery Dufftown in Banffshire, UK. The wastewater was pretreated in a series of tanks and a high rate trickling filter. The system was operated as free water surface system in 2007 and during this period the removal of copper load amounted to 85% while during the operation in the horizontal sub-surface flow mode, the removal amounted to only 53% in 2008. The removal of heavy metals from polluted waters can be achieved by the action of roots or other parts of aquatic plants [134].

4. Conclusion

The study showed that effluents from food processing industries contain extremely high levels of SS, COD, BOD_5, nitrate and phosphate. These values are mostly above the limits prescribed by WHO. They suggest that these effluents are not suitable to be discharged into natural ecosystems without treatment. However, their rich organic materials open the way for their biological treatment. As such, the purification performance of *Eichhornia crassipes* and *Panicum maximum* for the treatment of Fermencam's effluents showed good removal efficiency of PO_4^{3-}, SS, COD, BOD_5 and nitrate. However, the treatment is more efficient with *Eichhornia crassipes* than with *Panicum maximum* in the device behind Fermencam. A combination of both plants could make the treatment more effective with a view to enhance the value of this effluent in agriculture.

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