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Nutritional quality of *Solanum aethiopicum* L. Shum berry as affected by agroecological zones of production

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ABSTRACT— *Solanum aethiopicum* L. Shum (SAS) berries are consumed either raw or as in the form of a tea. This work was performed to study the chemical composition and microbial load of SAS berry harvested from five agroecological zones in Cameroon. The results showed that, berries freshly harvested from all the five agroecological zones were highly contaminated by microorganisms. Berries from the highlands and bimodal rainfall forest zones had a higher rate of contamination, while they were less contaminated in the sudano-sahelian zone. The berries were cleaned with sodium hypochlorite eliminating them from pathogenic microorganisms. The agroecological zones influenced the chemical composition of the SAS berries ($P < 0.05$), with exception of proteins and lipids ($P > 0.05$). These berries were more concentrated in the Sudano-sahelian zone and more hydrated in the monomodal rainfall forest zone. However, carbohydrates were the most abundant macronutrient irrespective of the place of production, bitter taste of berries is probably determined by their phytonutrients. Mineral salts such as calcium, magnesium, potassium varied following the agroecological zones, as well as trace-elements like zinc and manganese ($P < 0.05$), Compared to the iron which reminded unchanged irrespective of the place of production ($P > 0.05$). These results suggested that the chemical composition and microbial load of SAS depended on the agroecological zones, while confirming their richness in important nutrients.

KEYWORDS: *Solanum aethiopicum* Shum berries, contamination, microbial load, chemical composition, agroecological zones

1. INTRODUCTION

Solanum aethiopicum L. Shum is an annual and herbaceous plant that can reach 1,5 to 1,8 m in height, belonging to the Solanaceae family [1]. This plant is widespread in Central, West, East and Southern Africa; and widely cultivated in Uganda in the swamps during dry season [2]. It has strong stems and deep roots, and is drought resistant. The round berries are grouped in clusters on one side of the stem, their colour change from green to red during ripening. The diameter of berry varies between 1 and 2 cm. The seeds are flat and scattered in the pulp of the berry [3].

The berries of *S. aethiopicum* Shum are eaten raw or in the form of traditional tea known to the forest peoples of the Gulf of Guinea, as "*Mendim Me Zon*" [4], [5]. These berries are known detoxifying and revitalizing to the community. It is traditionally used to prevent cancer and diabetes [6]. Globally, many bioactivities are associated with species of *Solanum* gender, including anticancer, anti-inflammatory, antihyperlipidemic, antihyperglycaemic, antipyretic, antimicrobial, antihypertensive, neuro and hepatoprotective [7]. Numerous scientific evidences have been established functional and therapeutic virtues of *S. aethiopicum* Shum berries.

They are also used to treat parasitical [8] and metabolic syndrome diseases [9], [5]. The antiviral properties of these berries have highlighted one of the types of HIV [10]. These virtues have been attributed to their bioactive substances such as amins, carbohydrates, minerals, vitamins and secondary metabolites including calystegine alkaloids, phenolic compound, lectins and glycoalkaloids [11], [7]. Our study has previously shown that these berries possess proteolytic activity [12]. Adeyeye and Adanlawo [13] emphasised the amino acid profile of the berries of *S. aethiopicum* Shum. Recently, we proved that the consumption of *S. aethiopicum* Shum berry enhances the physical endurance of rats [14].

S. aethiopicum Shum plant grows in all the five agroecological zones of Cameroon, namely: bimodal rainfall forest; monomodal rainfall forest; highlands; guinean high savannah; and sudano-sahelian. Their berries are widely used for their virtues in food and pharmacopoeia. However, within the limits of our knowledge, no study has examined the nutritional quality of *S. aethiopicum* Shum berries in relation to the agroecological zones. Therefore, the objective of this work is to study the effect of agroecological zone of production on the chemical and microbiological quality of *S. aethiopicum* Shum berries.

2. Materials and methods

2.1 Materials

The berries harvested in the five agroecological zones of Cameroon: highlands (HZ); bimodal rainfall forest (BRFZ); monomodal rainfall forest (MRFZ); guinean high savannah (GHSZ) and sudano-sahelian (SSZ) precisely in the localities of Akum, Ambam, Tiko, Ngaoundere and Kaele respectively.

Berries were transported to the Laboratory of Food Biochemistry and Technology of the National Advanced School of Agro-Industrial Sciences, University of Ngaoundere; where they were sorted, washed with tap water, then distilled water and treated with 2% sodium hypochlorite solution. The washed berries were oven-dried at 40°C for 32 hours, ground to 1 mm particle size, packed in glass jars and kept in the freezer pending chemical and microbiological analyses.

2.2 Methods

2.2.1 Microbiological analyses of S. aethiopicum L. Shum berries

Microbiological analyses were carried out on the untreated and treated berry powder of *S. aethiopicum* L. Shum from each agroecological zone, as described above. The samples (1 g) were homogenized with buffered peptone water (phosphate pH 7), then diluted in the same solution (10^{-1} to 10^{-9}). The dilutions were then seeded on specific culture media for the enumeration of the residual flora or that of contamination on the berries after treatment. This is how the total mesophilic flora, coliforms, *Escherichia coli*, *Lactobacillus* Spp, *Staphylococcus aureus*, *Salmonella* Spp, *Clostridium* Spp and yeasts and moulds were counted. Petri dishes containing 15 to 150 colonies were considered. Three replicates of each sample were performed. The results were expressed in colony forming units per gram of berry.

2.2 Chemical analysis

2.2.1 Evaluation of macronutrients content in SAS berries

The water content of the fresh berries was evaluated by the method of AOAC 925.10 [15], it was dried at 105°C in infrared oven. The total ash content of the berries of *S. aethiopicum* L. Shum was determined by the method AOAC 920.87 [15]. This involved incinerating 3 to 5 g of sample in a muffle oven at 550 °C. The determination of the total protein content was carried out according to the method of Kjeldahl [15]. It is based on the transformation of organic nitrogen into mineral nitrogen in ammoniac form $(NH4)_2SO_4$ by the oxidative action of boiling sulphuric acid on organic matter in the presence of a catalyst. Lipids were determined by the method of Bourely [16]. This method is based on the complete extraction from the soxhlet of all the fatty substances present in a sample.

The sugars available in the fruits of *S. aethiopicum* were measured using the method described by [17]. The available carbohydrates were hydrolysed to simple sugars in an acid medium forming a red-brown complex (3-amino 5-nitrosalicylic acid) when hot and in the presence of 3, 5-dinitrosalicylic acid (DNS) which has a maximum of absorption at 540 nm.

2.2.2 Determination of minerals content in SAS berries

The mineral contents (Ca^{2+}, Na^{+}, K^{+}, Mg^{2+}, Fe^{2+}, Mn^{2+} and Zn^{2+}) were determined by the method described by Onwuliri & Anekwe [18]. This method consists of determining the mineral content by atomic absorption spectroscopy after solubilization of the ash from powdered *S. aethiopicum* L. Shum in an acid medium. The assay was carried out as follows: 1 g of ash was dissolved in 10 mL of concentrated hydrochloric acid, then the solution was filtered. 10 mL of lanthanum chloride (18 g of lanthanum oxide + 250 mL of concentrated HCl in 100 mL of distilled water) were added to the solution to extract the calcium and magnesium, and the volume was made up to 100 mL with distilled water [18]. The determination of the minerals was carried out using an atomic absorption spectrometer (Perkin-Elmer, AAS 1100 USA) powered by an air-acetylene flame.

2.2.3 Phytonutrients analysis

The total phenolic compounds were extracted in 70% ethanol and tested by the method of Marigo [19] using the reagent of Folin - Ciocalteu. The crude fibre content of *S. aethiopicum* L. Shum was determined by the AACC 32-07 method [20], with some modifications. The crude fibre content (Cf) was calculated by the following formula:

$$Cf = \frac{Mr - (Mrp + Ma)}{Sm} \times 100$$

Mr: mass of the residue; Mrp: mass of residual proteins; Ma: mass of ashes; Sm: sample material

2.2.4 Statistical analysis

All measurements were carried out in triplicate. Analysis of variance was performed to determine the effect of agroecological zone of production on the microbial load and chemical composition of SAS berry. When statistical differences were found, the Duncan's Multiple Range Test was applied in order to classify samples at the significant level of 5%. Statgraphics Program (Statically Graphics Educational, version 6.0 1992 Manugistics, Inc. and Statistical Graphics Corp., USA) was used for the statistical analysis.

3. Results and discussion

3.1 Microbial load

3.1.1 Microbial load of S. aethiopicum Shum berries before cleanliness

The table 1 presents the influence of the agroecological zone on microbial contamination of *S. aethiopicum* Shum (SAS) before cleanliness, and indicates the enumeration of mesophilic flora, total coliforms, *Escherichia coli*, *Lactobacillus* Spp, *Staphylococcus aureus*, *Salmonella* Spp, yeasts and fungi, and expressed in log10 (cfu/g). The SAS berries were contaminated regardless the agroecological zone. This contamination was low in the sudano-sahelian zone.

Escherichia coli load of the berries from the highlands and bimodal rainfall forest zones were not statistically different; but increased significantly in comparison with other zones (P < 0.05). The concentration in *Staphylococcus aureus* was significantly low for SAS berries produced in the bimodal rainfall forest and monomodal rainfall forest zones compared to berries from other zones (P < 0.05). The berries produced in the guinea high savannah, bimodal rainfall forest and rainfall forest zones had a significantly high concentration in *Salmonella* Spp compared to berries from highlands and sudano-sahelian zones (P < 0.05). The concentrations of yeast and fungi were statistically low in berries produced in the highlands zone (P < 0.05). In contrast, no statistical difference was noticed concerning *Lactobacillus* Spp (P > 0.05); and *Clostridium* Spp was absent in a gram of SAS berry. The total mesophilic flora was significantly high (9.8 ± 1.5) for the berries of the highlands zone compared to the other zones, and the lowest value (7.7 ± 1.6) was found to be berries from the Sudano-sahelian zone (P < 0.05).

The microbial contamination of berries in the field may be due to the humidity, wind, insect and animal. The rate of aerobic mesophilic germs is a measure which represents all the bacteria, moulds and yeasts existing in the product at the time of the analysis [21]. A high rate means that untimely contamination has occurred or developed. The raw SAS berries had an insufficient microbiologic hygiene to be used as food [22]. Eating the raw SAS berries exposes consumers to food-borne illnesses. For that reason, raw SAS berries requires a minimal treatment before any usage [23].

Table 1. Influence of agroecological zone on the microbial load of SAS berries before treatment.

	Agroecological zones*				
Microbial load ($\log_{10}$ (CFU/g)	HZ	BRFZ	MRFZ	GHSZ	SSZ
Mesophilic flora (10^6)	9.8 ± 1.5^a	8.3 ± 0.8^b	8.4 ± 1.3^b	8.5 ± 1.4^b	7.7 ± 1.6^b
Coliforms (10^4)	5.7 ± 0.5^a	5.2 ± 0.6^a	5.5 ± 0.3^a	5.1 ± 0.9^a	4.3 ± 0.3^b
Escherichia coli (10^4)	3.5 ± 0.7^a	3.6 ± 0.3^a	2.7 ± 0.5^b	2.3 ± 0.6^b	2.1 ± 0.5^b
Lactobacillus Spp (10^6)	5.4 ± 1.2^a	5.3 ± 1.4^a	5.7 ± 1.1^a	5.5 ± 1.7^a	5.8 ± 1.5^a
Staphylococcus aureus (10^4)	4.7 ± 1.2^a	2.7 ± 1.1^b	3.4 ± 0.7^b	4.6 ± 0.7^a	5.1 ± 1.5^a
Salmonella Spp (10^4)	3.9 ± 1.5^b	5.6 ± 0.7^a	4.5 ± 0.9^{ab}	4.8 ± 1.4^a	2.1 ± 1.5^c
Clostridium Spp	/	/	/	/	/
Moulds and yeast (10^4)	5.5 ± 1.0^a	6.4 ± 1.3^a	5.2 ± 1.2^{ab}	5.0 ± 0.9^b	4.6 ± 1.1^b

Means ± SD bearing different letters (a, b, c) indicate differences (P < 0.05) within the same row. (/) No germ.
* highlands (HZ); bimodal rainfall forest (BRFZ); monomodal rainfall forest (MRFZ); guinean high savannah (GHSZ) and sudano-sahelian (SSZ)

3.1.2 Microbial load of SAS berries after treatment

Microbial load of SAS berries substantially diminished (Table 2), when they were disinfected with sodium hypochlorite solution (2%). Pathogenic microorganisms as coliforms, E*scherichia coli, Clostridium* Spp, *Staphylococcus aureus* and *Salmonella* Spp were absent in the disinfected SAS berry. The mesophilic flora expressed in CFU/g 10^5 was significantly (p < 0 .05) low (6.3 ± 0.8) in berries produced in the SSZ zone compared to other zones: 7.9 ± 0.5 (BRFZ); 8.4 ± 0.9 (MRFZ); 8.5 ± 0.6 (GHSZ) and 10.2 ± 0.7 (HZ). The concentration of *Lactobacillus* Spp (CFU/g 10^3) significantly (p < 0 .05) varied from 3.4 ± 0.9 (HZ) to 5.7 ± 0.6 (MRFZ). Moulds and yeasts also varied significantly (p < 0 .05) from 37.0 ± 8.1 (SSZ) to 58 ± 3.8 (HZ).

These results suggest that treating the berries with a sodium hypochlorite solution cleared them of pre-existing pathogenic microorganisms. Whatever the agroecological zone, the berries can be eaten raw after disinfection. In any case, the populations prefer to transform these berries into traditional tea (so called "*Medim Me Zon*"), in order to avoid any food toxi-infection and benefit from its virtues.

Table 2: Influence of the agroecological zones on the residual microbial load of SAS berries after treatment

Microbial load log (CFU/g)	Agroecological zones*				
	HZ	BRFZ	MRFZ	GHSZ	SSZ
Mesophilic flora (10^5)	10.2 ± 0.7^a	7.9 ± 0.5^b	8.4 ± 0.9^b	8.5 ± 0.6^b	6.3 ± 0.8^c
Coliforms	/	/	/	/	/
Escherichia coli	/	/	/	/	/
Lactobacillus Spp (10^3)	3.4 ± 0.9^c	5.7 ± 0.6^a	4.4 ± 0.5^{bc}	5.5 ± 0.7^{ab}	4.1 ± 0.8^c
Staphylococcus aureus	/	/	/	/	/
Salmonella Spp	/	/	/	/	/
Clostridium Spp	/	/	/	/	/
Moulds and yeasts	58.8 ± 3.8^a	41.3 ± 3.3^b	42.8 ± 6.4^b	47.9 ± 5.7^b	37.0 ± 8.1^c

Means ± SD bearing different letters (a, b, c) indicate differences ($P < 0.05$) within the same row.
(/) No germ
* highlands (HZ); bimodal rainfall forest (BRFZ); monomodal rainfall forest (MRFZ); guinean high savannah (GHSZ) and sudano-sahelian (SSZ)

3.2 Effect agroecological zone on the chemical composition of the SAS berry

3.2.1 Effect agroecological zone on the proximate composition of the SAS berry

The chemical composition of the SAS berries was determined with respect to five agroecological zones in Cameroon. Table 3 presents the effect of agroecological zones on the proximate composition of SAS berries including: humidity, ashes, lipids, proteins, soluble proteins and carbohydrates. The water content varied from 88.28 ± 0.64 (SSZ) to 91.69 ± 0.53 (MRFZ) g/100 g. Similar values had been observed in berry from close specie [24]. The agroecological zones significantly influenced the humidity due to pedological and climatic variability. The same trend has been observed for ash, carbohydrates and total proteins. The concentration of ash in the SAS berry was situated between 0.63 ± 0.05 (MRFZ) and 0.89 ± 0.02 g/100 g (SSZ). These values were inferior to those observed in *Solanum melongena* [25]. The carbohydrates were the major component in the SAS berry, varying from 3.35 ± 0.22 (MRFZ) and 4.44 ± 0.46 g/100 g (ZSS), while they are bitter taste. The same tendency was observed by [24]; meanwhile [25] found an opposite trend. Total protein varied from 1.31 ± 0.12 (MRFZ) to 2.01 ± 0.15 g/100 g (SSZ). The concentration in lipids and soluble proteins did not show a statistical difference in function of the agroecological zone ($P > 0.05$). The biological activity and stability of these macronutrients depend on the interactions that they establish with berries minerals or with the milieu of extraction when they are extracted from fruits [26].

Table 3. Influence of the agroecological zone on the proximate composition of SAS berries

Agroecological zones*

Parameters (g/100g)	HZ	BRFZ	MRFZ	GHSZ	SSZ
Moisture	90.14 ± 0.21[b]	89.98 ± 0.52[b]	91.69 ± 0.53[a]	88.98 ± 0.62[c]	88.28 ± 0.64[c]
Ashes	0.72 ± 0.06[b]	0.85 ± 0.05[a]	0.63 ± 0.05[c]	0.88 ± 0.01[a]	0.89 ± 0.02[a]
Carbohydrates	3.65 ± 0.44[bc]	3.99 ± 0.09[ab]	3.35 ± 0.22[c]	3.97 ± 0.24[ab]	4.44 ± 0.46[a]
Lipids	0.22 ± 0.05[a]	0.24 ± 0.05[a]	0.25 ± 0.05[a]	0.25 ± 0.07[a]	0.29 ± 0.06[a]
Total proteins	1.91 ± 0.20[a]	1.76 ± 0.32[a]	1.31 ± 0.12[b]	1.81 ± 0.09[a]	2.01 ± 0.15[a]
Soluble proteins	0.31 ± 0.01[a]	0.30 ± 0.02[a]	0.29 ± 0.02[a]	0.31 ± 0.01[a]	0.31 ± 0.02[a]

Means ± SD bearing different letters (a, b, c) indicate differences (P < 0.05) within the same row.
* highlands (HZ); bimodal rainfall forest (BRFZ); monomodal rainfall forest (MRFZ); guinean high savannah (GHSZ) and sudano-sahelian (SSZ)

3.2.2 Effect of agroecological zone on elemental composition of the SAS berry

Table 4 presents the influence of the agroecological zone on the elemental composition of SAS berry. The variation of calcium, magnesium, sodium, potassium, manganese, iron, and zinc were significant in function of the place of production ($P < 0.05$). The values (mg/100 g) were situated between 27.07 ± 1.25 (BRFZ) and 33.24 ± 2.38 (HZ); 272 ± 9.57 (GHSZ) and 362 ± 6.45 (MRFZ); 177 ± 12.84 (BRFZ) and 220 ± 6.50 (MRFZ); 17.46 ± 0.54 (GHSZ) and 33.24 ± 2.38 (SSZ); 0.23 ± 0.02 (SSZ) and 0.31 ± 0.01 (MRFZ); 0.81 ± 0.04 (MRFZ) and 0.99 ± 0.12 (HZ); 0.20 ± 0.02 (HZ) and 0.30 ± 0.01 (BRFZ) respectively for calcium, magnesium, sodium, potassium, manganese, iron and zinc. Minerals like calcium, zinc, manganese, sodium, magnesium and potassium are implicated in the metabolism of carbohydrates, proteins and lipids. The results suggest that these SAS berries were rich in mineral salts and trace elements, favourable for their optimal biological activity.

Table 4 Influence of the agroecological zone on the minerals content of the SAS berries

Parameters (mg/100g)	Agroecological zones* HZ	BRFZ	MRFZ	GHSZ	SSZ
Calcium	33.24 ± 2.38[a]	27.07 ± 1.25[c]	32.00 ± 3.56[a]	30.87 ± 0.97[ab]	28.27 ± 1.49[bc]
Sodium	317 ± 6.68[b]	300 ± 10.84[c]	362 ± 6.45[a]	272 ± 9.57[d]	349 ± 8.52[a]
Potassium	204 ± 8.26[b]	177 ± 12.84[c]	220 ± 6.50[a]	209 ± 3.77[ab]	181 ± 7.23[c]
Magnesium	21.92 ± 2.37[a]	19.87 ± 0.96[ab]	19.63 ± 1.29[ab]	17.46 ± 0.54[b]	33.24 ± 2.38[ab]
Manganese	0.28 ± 0.05[a]	0.24 ± 0.01[b]	0.31 ± 0.01[a]	0.30 ± 0.02[a]	0.23 ± 0.02[b]
Iron	0.99 ± 0.12[a]	0.84 ± 0.15[a]	0.81 ± 0.04[a]	0.87 ± 0.17[a]	0.98 ± 0.11[a]
Zinc	0.20 ± 0.02[d]	0.30 ± 0.01[a]	0.27 ± 0.01[bc]	0.29 ± 0.02[ab]	0.25 ± 0.01[c]

Means ± SD bearing different letters (a, b, c) indicate differences (P < 0.05) within the same row.
* highlands (HZ); bimodal rainfall forest (BRFZ); monomodal rainfall forest (MRFZ); guinean high savannah (GHSZ) and sudano-sahelian (SSZ)

3.2.3 Effect of agroecological zone on the phytonutrients of SAS berries

Phytonutrients of SAS berries including fibres and phenolic components have been evaluated in function of agroecological zone. The phytonutrients of SAS berries have been affected by agroecological zone (table 5). Fibres and phenolic components varied from 1.76 ± 0.37 (MRFZ) to 2.80 ± 0.21 (SSZ) and from 0.12 ± 0.01 (MRFZ) to 0.18 ± 0.03 g/100 g (SSZ) respectively. Bitter taste of SAS berries is probably determined by their phytonutrients, despite the fact that carbohydrates are major component of these fruits. Concentrations of 110 mg/100g of phenolic compounds were found into immature berries of a specie of SAS [11]. The virtues of SAS berries are often attributed to their phytonutrients [5]. However, the bioactivity of potentially toxic substances such as solanins can lead to food poisoning. In order to food-borne diseases and to take advantage of the benefits of these berries, the Bantu people process them into a traditional tea, called "*Mendim Me zon*"

Table 5. Effect of agroecological zone on the phytonutrients of SAS berries

Parameters (g/100g)	Agroecological zones*				
	HZ	BRFZ	MRFZ	GHSZ	SSZ
Fibres	2.28 ± 0.19^{bc}	1.92 ± 0.14^{cd}	1.76 ± 0.37^{d}	2.66 ± 0.38^{ab}	2.80 ± 0.21^{a}
Polyphenols	0.15 ± 0.08^{ab}	0.13 ± 0.07^{b}	0.12 ± 0.01^{b}	0.17 ± 0.04^{a}	0.18 ± 0.03^{a}

Means ± SD bearing different letters (a, b, c) indicate differences ($P < 0.05$) within the same row.
* highlands (HZ); bimodal rainfall forest (BRFZ); monomodal rainfall forest (MRFZ); guinean high savannah (GHSZ) and sudano-sahelian (SSZ)

4. Conclusion

This work showed that the agroecological zone of production influences the microbial load and chemical composition of *Solanum aethiopicum* Shum berries. Untreated berries are contaminated with pathogenic microorganisms that can cause food-borne diseases. Sodium hypochlorite solution is effective in the sanitation of S. aethiopicum Shum berries. These berries are rich in macronutrients, minerals and phytonutrients, which vary following the agroecological zone of production. Berries are more concentrated in sudano-sahelian zone, and less in monomodal rainfall forest zone. Carbohydrates are major component of these berries, its taste is always bitter; probably determine by phytonutrients. This justifies why tea from these berries is nutraceutical among forest people. Others studies will be necessary to evaluate the nutraceutical potential of this tea, call "*Medim Me Zon*" in mother tongue.

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Conflict of interest
The authors declare that there is no conflict of interest regarding these results.

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