Original research article

Microbiological contamination levels of tomatoes produced and sold in Niamey, Niger: A Comparative analysis

Abstract:

Fruits and vegetables are an important food source of nutrients, vitamins and fiber, and play a vital role in human health and well-being. They are also recommended for reducing the risk of several diseases. This study aims to assess the microbiological quality of a few samples of tomatoes produced and sold in Niamey. To this end, contamination indicator germs such as Total Aerobic Mesophilic Flora (FAMT), Total Coliforms (TC), Faecal Coliforms (FC), Enterobacteriaceae (ENTR), Faecal Streptococci (FS), Clostridium perfringens (CP) and Escherichia coli (E. coli) were enumerated, using methods specific to each germ. Analysis of the results shows that market 4 samples were heavily contaminated with FAMT, CT, CF, Ent and SF (7.06, 5.93, 5.74, 6.31 and 6.06 Log10 CFU/g of tomato respectively), market 1 with CP (5.12 Log10 CFU/g) and market 5 with E. coli (5.35 Log10 CFU/g). Twelve (12) species of enterobacteria were identified, including Enterobacter cloacae, Escherichia coli1, Escherichia vulneris, Pantoea spp 1, Providencia stuartii, Salmonella spp, Salmonella arizonae and Serratia liquefaciens. The sanitary quality of these vegetables is poor. That's why it's essential to follow good hygiene practices in the market, to ensure a healthy vegetable.

Keywords: vegetable, quality, microbiological, tomato, Niamey/Niger

INTRODUCTION

Africa's urban and peri-urban areas are favorable for growing fruit and vegetables, contributing to food security and job creation for many low-income households (Koffi-Nevry *et al*., 2012, Maïwore *et al*., 2020, Almou *et al*., 2024). Fruits and vegetables are an important dietary source of nutrients, vitamins and fiber, and also play a vital role in human health and well-being (Kalia *et al.,* 2006). Consumption of fruit and vegetables is recommended in several countries for protection against various diet-related chronic non-communicable diseases such as certain forms of cancer, obesity, cardiovascular disease, and the benefits of their dietary fiber are also recognized in the smooth functioning of intestinal transit (Idogun *et a*l., 2008 ; Berger *et al*., 2010 ; Wognin *et al*., 2013 ; Almou *et al*., 2024).

The tomato (*Solanum lycopersicum L*.) is a fruit in the botanical sense, but is eaten as a vegetable. Raw, it can be eaten plain in a salted crust, in a vegetable salad or as a puree. Cooked, tomatoes are most often eaten in sauce (PPEAP, 1999). Today, tomato production is the world's second-largest vegetable crop, and consumption is constantly on the rise, at over 15kg per capita per year. The plant

is grown under glass and in open fields, on a surface area of around 3 million hectares, which represents almost 1/3 of the world's surface area devoted to vegetables. Tomatoes have given rise to a major processing industry, producing concentrates, sauces, juices and preserves (Alioui et Segni, 2020).

In Niger, tomatoes can be found in several off-season locations. Production is highest around the big cities. Urban and peri-urban areas are major tomato producers (PPEAP, 1999). Tomatoes are mainly produced for a maximum of 6 months (January to June), with Niger exporting them during the dry season and importing them during the rainy season (RECA, 2016). In Niamey, these vegetables are eaten raw in the form of salads, as hors d'oeuvres or as accompaniments to main courses or as condiments in sauces. Despite the benefits associated with the consumption of this fruit, the safety of those consumed fresh remains a major concern, as these foods are considered vectors for the transmission of infectious diseases (Toe *et al*., 2017). The overall objective of this study is to contribute to the improvement of the hygienic quality of tomatoes product and sold in the urban community of Niamey (Niger).

1. MATERIALS AND METHODS

1.1. Study area

The study was carried out in the urban community of Niamey, the capital of the Republic of Niger. The urban community of Niamey is located in the south-western part of Niger, between 13°24' and 13°35'N latitude and 2°00' and 2°15'E longitude, with an altitude of between 160 and 250 m. Its administrative boundaries cover 552.27 km², including around 297.46 km² of urbanized area. Niamey's population is estimated at around 1,407,635 (INS, 2018). The urban community of Niamey is subdivided into 5 communal districts, with the following population breakdown by communal district: Niamey I: 287,902 inhabitants; Niamey II: 338,455 inhabitants; Niamey III: 223,685 inhabitants; Niamey IV: 376,271 inhabitants; Niamey V: 181,321 inhabitants (INS, 2022). Five (5) Niamey vegetable markets were studied (Harobanda market, small market, Wadata market, Dolé market and Dar Es Sallam market) and one market garden (Harobanda site) (fig. 1).

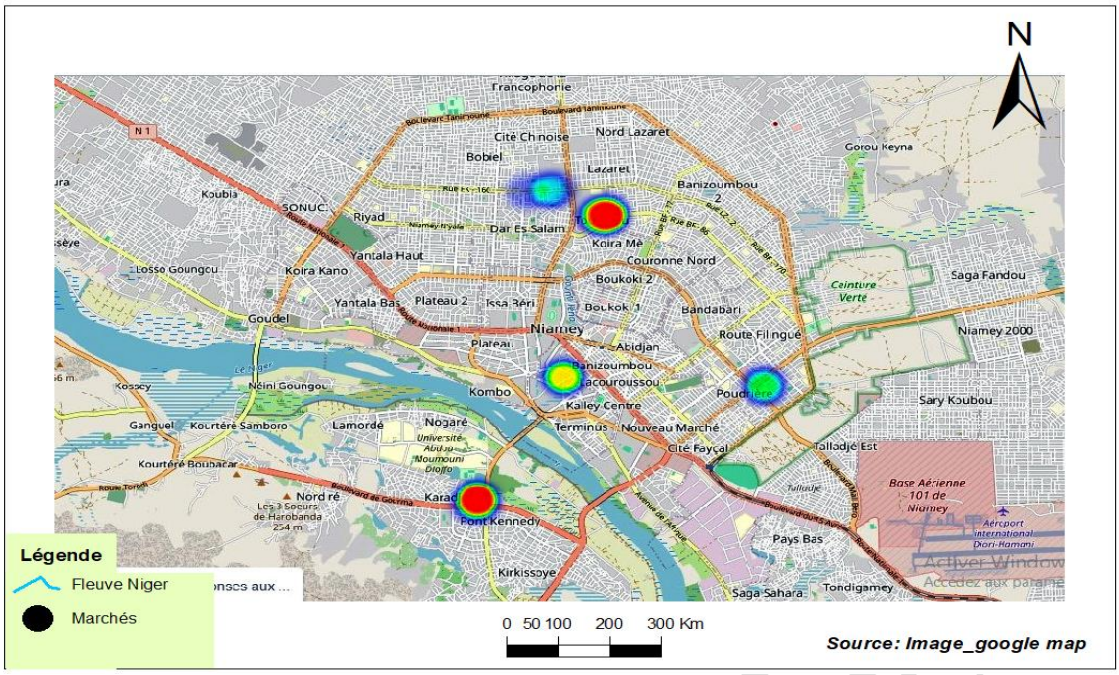

Figure1: Map of the city of Niamey, which contains the markets used in the study

1.2. Sampling method and transport conditions

Tomato samples were taken at five (5) markets and one market garden in the urban community of Niamey. A sample corresponds to three (3) fruits without cracks, weighing around 150g, taken at random from different corners of the production site or from the same vendor's lot. A total of 35 tomato samples were taken (Table I). An information sheet was attached to each sample. Each sample collected was well packaged in a polyethylene bag, then carefully labelled. The samples were transferred to the microbiology laboratory of the Faculty of Science and Technology (FAST), after being packaged and placed in a cooler containing carboglass to keep the temperature down to around 4°C.

Table I. Market garden sites and vegetable markets sampled

Arrondissements communaux	**Selected sites**			
	Name	Quartier	Site	Samples number
Arrondissement 1	Petit marché	Zango	Market 1	8
Arrondissement 2	Dar es salam	Koura me	Market 2	7
Arrondissement 2	Dolé	Koura me	Market 3	8
Arrondissement 3	Wadata	Wadata	Market 4	2
Arrondissement 4	-	-	-	-
Arrondissement 5	Harobanda	Karajé	Market 5	4
			Market garden site	6
Total				35

1.3. Bacteriological analysis

Stock solution preparation: the stock solution was prepared by grinding each tomato sample. Next, 25 grams of the grindings were removed and placed in 225 mL of previously prepared and sterilized buffered peptone water. Then, 1 mL of each stock solution was taken and introduced into a test tube containing 9 mL of buffered peptone water for the various decimal dilutions.

Bacterial culture: The indicators of contamination sought were Total Aerobic Mesophilic Flora (TAMF), Coliforms (Total and Faecal), Faecal Streptococci (FS), Clostridium perfringens (CP), Escherichia coli (*E. coli*), and Enterobacteriaceae (Ent).

- Total Aerobic Mesophilic Flora (TAMF) was enumerated in accordance with ISO V08051(1992) / ISO 4833. This flora was counted on PCA (Plat Count Agar). Incubation was carried out at 37° C for 24 hours.
- Coliforms were tested on VRBL (Violet Red Bille Lactose Agar) medium by incubation at 37°C for 24 hours for total coliforms and 44°C for fecal coliforms. Characteristic colonies were counted in accordance with ISO 4832 (February, 2006). Coliforms showed purplish colonies with a diameter equal to or greater than 0.5 mm after 24 hours incubation.
- Fecal streptococci were counted on KAA (Kanamycin-Asculin-Azid-Agar) agar in accordance with AFNOR NF 190-0411, 1989. Incubation was at 37°C for 24 hours. Fecal streptococci appeared as small translucent colonies surrounded by black halos.
- Clostridium perfringens was counted on TSN (Tryptone-Sulfite Neomycin) agar in accordance with the ISO 7937 standard. A first reading was taken after 24 hours to prevent total blackening of the tube, followed by a second reading after 48 hours, when the large colonies visible in the tube were counted.
- E. coli were counted on EMB (Methylene Blue Eosin) agar according to ISO 18140. After incubation at 37°C for 24 hours, characteristic E. coli colonies (green with a metallic sheen) were counted.

- Enterobacteria were counted on Mac Conkey agar in accordance with ISO 21528-1. Inoculation was carried out by spreading 0.1 mL of each dilution onto Mac Con key agar, which had been poured into Petri dishes. The plates were incubated at 37°C for 24 hours. Brick-red and purplish colonies characteristic of Enterobacteriaceae were counted.
- *Enterobacteriaceae* identification: *Enterobacteriaceae* from tomato samples were randomly selected and streaked onto nutrient agar. Biochemical characterization was carried out on Api 20 E strips. Strains were identified by comparing their characteristics with those of known taxa as described in the bio Mérieux SA manual.

1.4. Interpretation

Bacterial load was calculated in accordance with ISO 7218 (2007) using the following formula:

$$N = \frac{\Sigma c}{(n1+0,1xn2)v.d}$$

- Σc = Total number of colonies counted in boxes with colonies between 15 and 300 ;
- n1 = number of boxes counted from the first dilution;
- n2 = number of boxes counted in the second dilution;
- d = dilution factor from which the 1st counts were made;
- v = inoculum volume.

1.5. Statistical analysis

Data were subjected to frequency, mean and standard deviation calculations using IBM SPSS Statistics 23 software. Then the (ANOVA) test was performed to test not only the variability between different samples from one sampling site to another, but also the variability between different samples of the same vegetable type. The Duncan test was used for the multiple comparison of averages. In addition, a hierarchical ascending classification (HAC) based on Euclidean distance using Ward's method, a Discriminant Factor Analysis (DFA) and Correspondence Factor Analysis (CFA) were carried out to determine whether samples from different sampling sites are similar or dissimilar on the STATA software. Differences are considered significant for P-value < 0.05. Finally, Microsoft Excel was used to generate the graphs.

2. RESULTS

2.1. Spatial variations of contamination levels in tomato samples

Figure 2 shows the variation of contamination indicators for tomato samples from market 1 (Petit marché) and field (Harobanda market garden site). Contamination levels vary significantly from one indicator to another (P-value = 0.004). Mean loads ranged from 2.1 Log10 CFU/g tomato (*E. coli*) to 5.99 Log10 CFU/g (faecal streptococci) in the market and from 2.88 Log10 CFU/g (E. coli and faecal coliforms) to 5.40 Log10 CFU/g in the field. Contamination levels in samples from Market 1 were higher (CT, CF, SF and CP respectively 5.11; 4.95; 5.35; 5.99 and 5.12 Log10 CFU/g tomato) than in the field.

In contrast, FAMT and *E. coli* contamination levels (2.88 and 5.40 Log10 CFU/g tomato) of samples from the field are higher than those from Market 1.

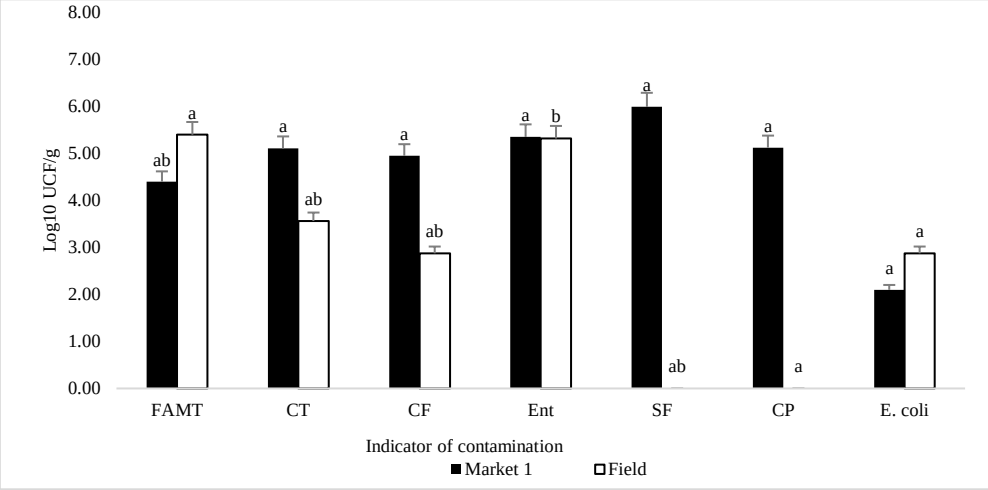

Figure 2. variation of contamination indicators for market 1 (small market) and field (Harobanda site) *(FAMT: Total Aerobic Mesophilic Flora; CT: total coliforms; CF: faecal coliforms; Ent: enterobacteria; SF: faecal streptococci; E. coli: Escherichia coli);* The values of the same indicator affected by the same letter are not significantly different.

Figure 3 show the variations of contamination indicators for market 2 (Dolé market) and the field. Contamination levels varied significantly from one indicator to another (P-value = 0.004). High levels of contamination were recorded on market 2 for CT, CF, Ent, SF and *E. coli* (around 5.17; 5.27; 5.53; 4.38; and 4.54 Log10 CFU/g of tomato). These loads are well above the standards defined by AFNOR [16] for vegetables consumed raw. In addition, samples from Market 2 were more contaminated than field samples, whatever the contamination indicator considered.

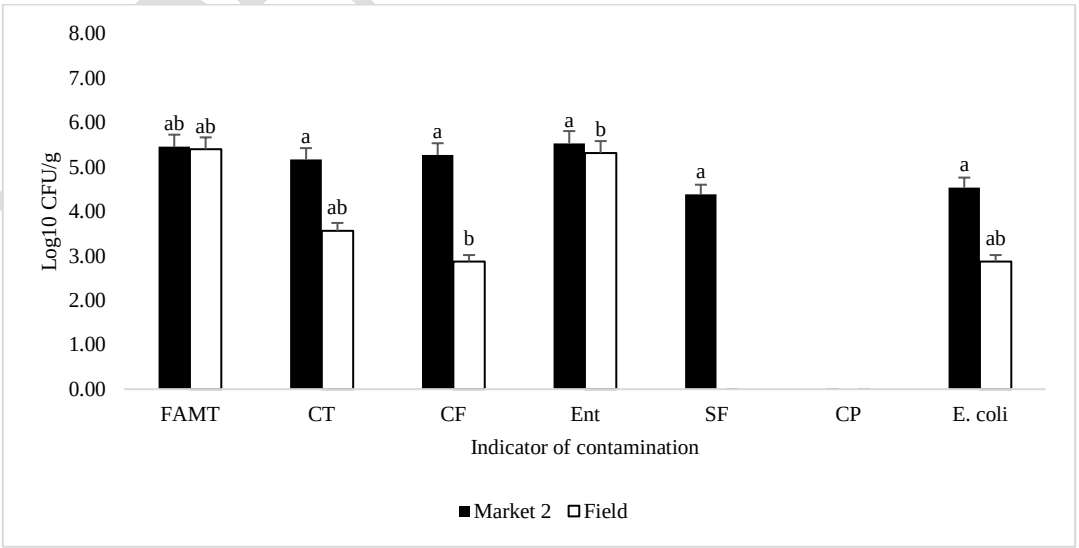

Figure 3. variation in contamination indicators for market 1 (Harobanda) and market garden site (field) (*FAMT: Total Aerobic Mesophilic Flora; CT: total coliforms; CF: faecal coliforms; Ent: enterobacteria; SF: faecal streptococci; E. coli: Escherichia coli*); The values of the same indicator affected by the same letter are not significantly different.

Variations of contamination levels of tomato samples from market 3 (Dar es Salam market) and the field are shown in **figure 4**. Differences are significant from one contamination indicator to another (P-value = 0.019). Samples from market 3 are highly contaminated whatever the contamination indicator considered, and higher than those from the field. However, the average load of FAMT (5.68 Log10 CFU/g tomato) is slightly below the microbiological criteria defined by AFNOR (5.10^5 CFU/g = 5.69 Log10 CFU/g). However, *Clostridium perfringens* was absent from market 3 and field samples, and fecal streptococci from field samples.

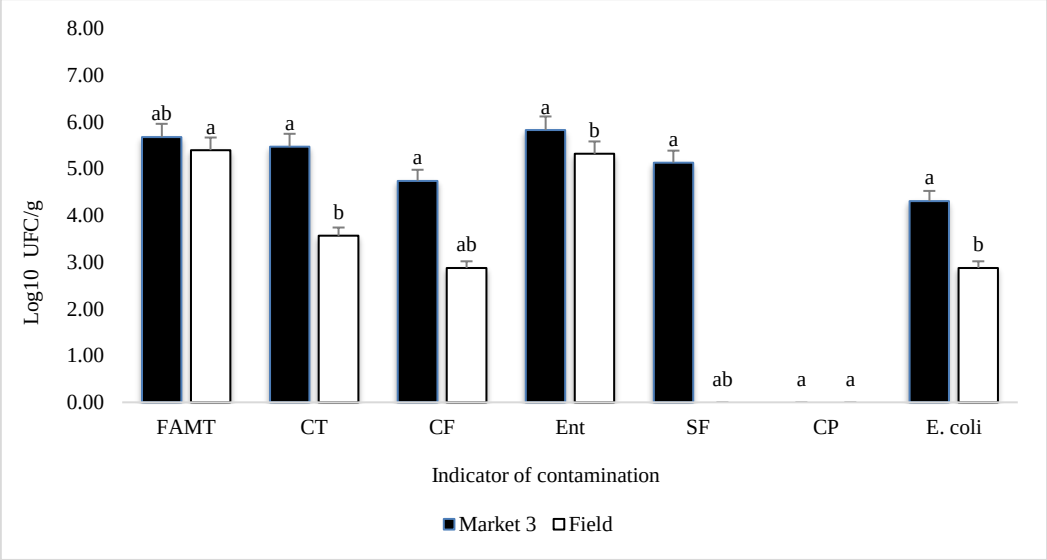

Figure 4. Variation of contamination levels for market 3 (Dar es salam market) and market garden site (field) (*FAMT: Total Aerobic Mesophilic Flora; CT: total coliforms; CF: faecal coliforms; Ent: enterobacteria; SF: faecal streptococci; E. coli: Escherichia coli*); The values of the same indicator affected by the same letter are not significantly different.

Figure 5 show the variation of contamination levels for tomato samples from market 4 (Wadata market) and market site. The variation of contamination levels between indicators is significant (P-value = 0.644). Average loadings were well above standards, especially for AFMT (7.06 Log10 CFU/g of tomato), fecal coliforms (5.74 Log10 CFU/g of tomato), fecal streptococci (6.06 Log10 CFU/g of tomato) and *Clostridium perfringens* (3.18 Log10 CFU/g of tomato). Fecal streptococci and *Clostridiums perfringens* were absent from field samples. However, whatever the contamination indicator considered, contamination levels in Market 4 samples are higher than those in the field.

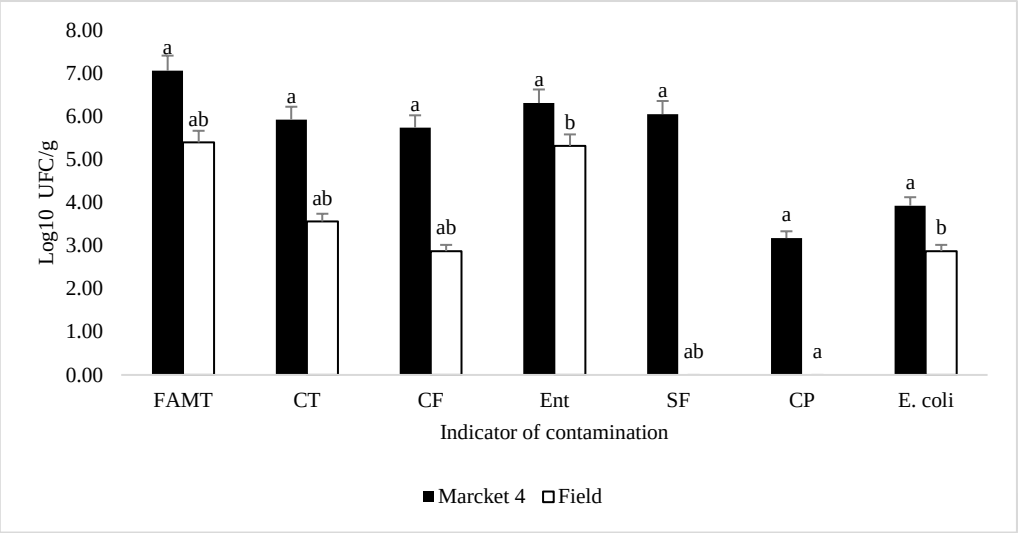

Figure 5. Variation of contamination levels for market 4 (Wadata market) and market garden site (field) (*FAMT: Total Aerobic Mesophilic Flora; CT: total coliforms; CF: faecal coliforms; Ent: enterobacteria; SF: faecal streptococci; E. coli: Escherichia coli*); The values of the same indicator affected by the same letter are not significantly different.

Figure 6 shows the variations of contamination levels for tomato samples from Marché 5 (Harobanda market) and the field. The differences of contamination levels are non-significant between contamination indicators (P-value = 0.530). Contamination levels in Market 5 ranged from 4.75 Log10 CFU/g, (SF) to 6.00 Log10 CFU/g of tomato (FAMT). The average loads are well above the standards for all indicators. However, contamination levels in Market 5 samples are higher than in the field for all contamination indicators.

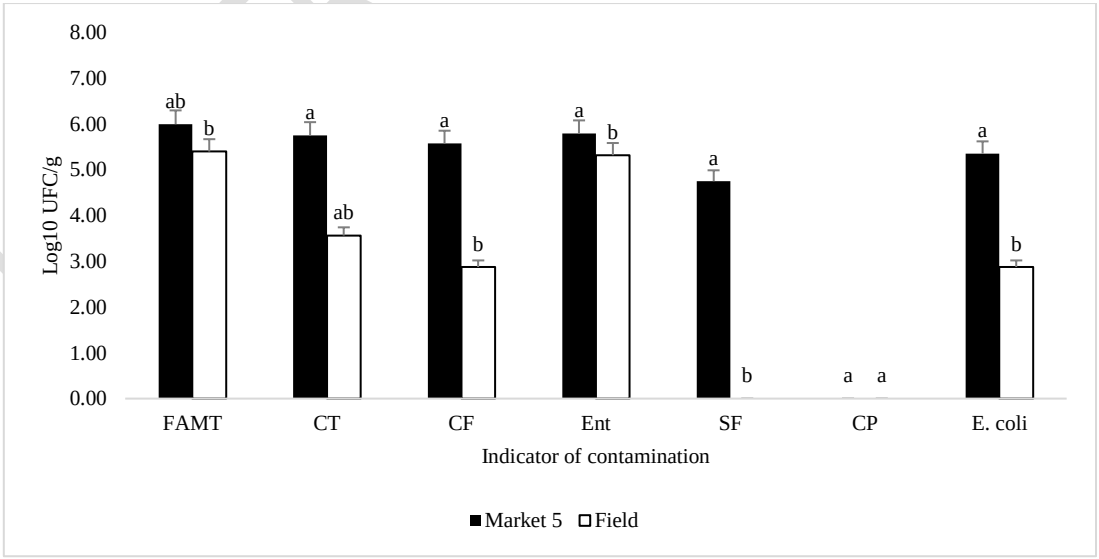

Figure 6. Variation in contamination indicators for market 5 (Harobanda market) and market garden site (field) (*FAMT: Total Aerobic Mesophilic Flora; CT: total coliforms; CF: faecal coliforms; Ent:*

enterobacteria; SF: faecal streptococci; E. coli: Escherichia coli); The values of the same indicator affected by the same letter are not significantly different.

2.2. Comparative analysis of market variations of contamination levels

Figure 7 compares the contamination levels of tomato samples from the five (5) markets included in the study. FAMT loads varied significantly from one market to another (P-value = 0.048). Market 1 had the lowest FAMT load (4.40 Log10 CFU/g of tomato) and market 4 the most contaminated (7.05 Log10 CFU/g of tomato). The variation in average TC load was insignificant between markets (P-value = 0.165). CT contamination levels ranged from 5.11 Log10 CFU/g (market 1) to 5.93 Log10 CFU/g tomato (market 4). Variations of CF contamination levels were insignificant between markets (P-value = 0.521). Market 3 has the lowest level of CF contamination (4.74 Log10 CFU/g tomato) and market 4 the highest (around 5.74 Log10 CFU/g tomato). SF contamination levels varied significantly between markets (P-value = 0.038). The highest level of contamination was observed in market 4 (around 6.06 Log10 CFU/g of tomato), and the lowest in market 2 (around 4.38 Log10 CFU/g of tomato). Finally, market 5 had the highest level of *E. coli* contamination (5.35 Log10 CFU/g tomato), while market 1 had the lowest (2.10 Log10 CFU/g tomato). Variations of *E. coli* contamination levels are not significant (P-value = 0.068). Market 4 is more contaminated with FAMT, CT, CF, Ent and SF, and market 5 with *E. coli*. However, market 1 is less contaminated with FAMT, CT, Ent and *E. coli*.

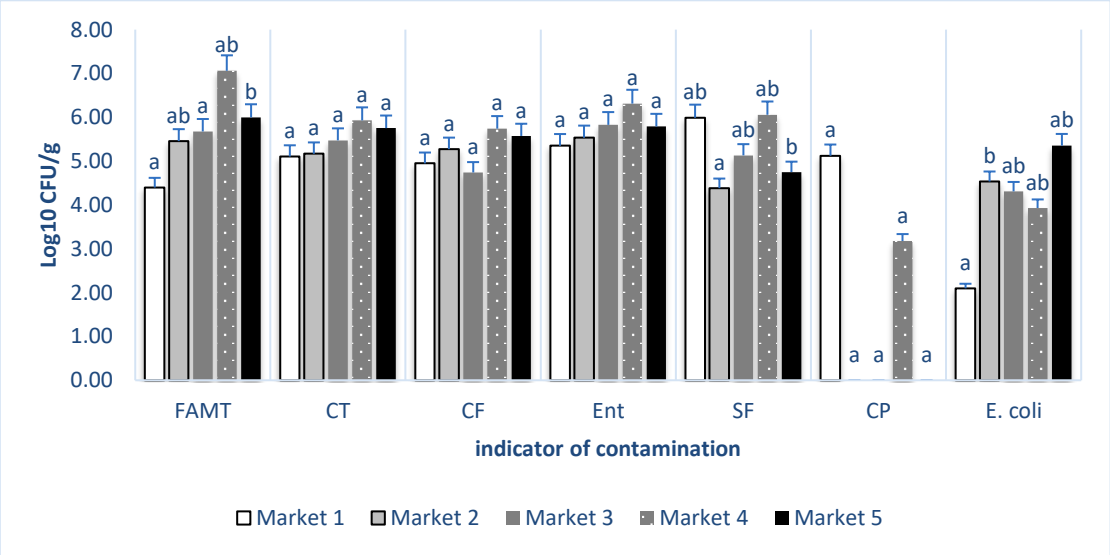

Figure 7. Variation of contamination levels by market; The values of the same indicator affected by the same letter are not significantly different.

2.3. Person's correlation between contamination indicators

Table II shows the Person correlations calculated between the various contamination indicators. Several significant correlations at the 5% level were recorded. Among these significant correlations, two (2) were positive, the first between fecal streptococci and fecal coliforms (r = 0.628 and P-value = 0.021) and the second between *Clostridiums perfringens* and fecal streptococci (r = 0.979 and P-value = 0.021). However, several significant negative correlations at the 5% level alone were recorded between

Clostridium perfringens and FAMT (r = -0.981 and P-value = 0.019), CT (r = -0.951 and P-value = 0.049) and Ent (r = -0.977 and P-value = 0.023) and between *E. coli* and faecal streptococci (r = -0.911 and P-value = 0.012). In addition, three (3) strong positive correlations significant at the 10% threshold were recorded between CF and CT (r = 0.932 and P-value = 0.000), Ent and CT (r = 0.978 and P-value = 0.000), Ent and CF (r = 0.929 and P-value = 0.000) and between E. coli and CP (r = 1)

Table II. Person's correlation between contamination indicators

		FAMT	**CT**	**CF**	**Ent**	**SF**	**CP**	***E. coli***
FAMT	r	1						
	P-value	-						
CT	r	0,303	1					
	P-value	0,395	-					
CF	r	0,148	0,932**	1				
	P-value	0,646	0,000	-				
Ent	r	0,448	0,978**	,929**	1			
	P-value	0,194	0,000	0,000	-			
SF	r	-0,080	0,260	**0,628***	0,331	1		
	P-value	0,805	0,440	**0,021**	0,320	-		
CP	r	**-0,981***	**-0,951***	-0,519	**-0,977***	**0,979***	1	
	P-value	**0,019**	**0,049**	0,481	**0,023**	**0,021**	-	
E. coli	r	-0,876	-0,031	-0,310	-0,157	**-0,911***	1,000**	1
	P-value	0,052	0,924	0,327	0,626	**0,012**	-	-

2.4. Diversity of enterobacteria isolated from tomato samples

Table III shows the diversity of enterobacteria species isolated from tomato samples. A total of twelve (12) strains of enterobacteria were identified, divided into 9 species belonging to six (6) genera. The species identified were *Enterobacter cloacae, Escherichia coli 1* and 2, *Escherichia vulneris, Pantoea spp1, Providencia stuartii, Salmonella enterica, Salmonella spp* and *Serratia liquefaciens*.

Table III. Diversity of enterobacteria isolated from tomato samples

Espèces d'entérobactéries identifiées	**Nombre (n)**	**Fréquence (%)**
Enterobacter cloacae	2	16,67[a]
Escherichia coli1	2	16,67[a]
Escherichia coli2	1	08,33[a]
Escherichia vulneris	1	08,33[a]
Pantoea spp 1	1	08,33[a]
Providencia stuartii	1	08,33[a]
Salmonella arizonae	1	08,33[a]

Salmonella spp	2	16,67[a]
Serratia liquefaciens	1	08,33[a]
Total	**12**	**100**

2.5. Study of the biochemical similarity of the strains identified

Hierarchical Ascending Classification (HAC) of the biochemical characteristics of the Enterobacteriaceae strains identified based on Jaccard's index using Ward's method identified three (3) groups (**figure 8**). Group 1 represents 58.33% of all strains identified from tomato samples. Group 2 accounts for 25%, and the third and smallest group represents 16.17% of the bacterial population identified.

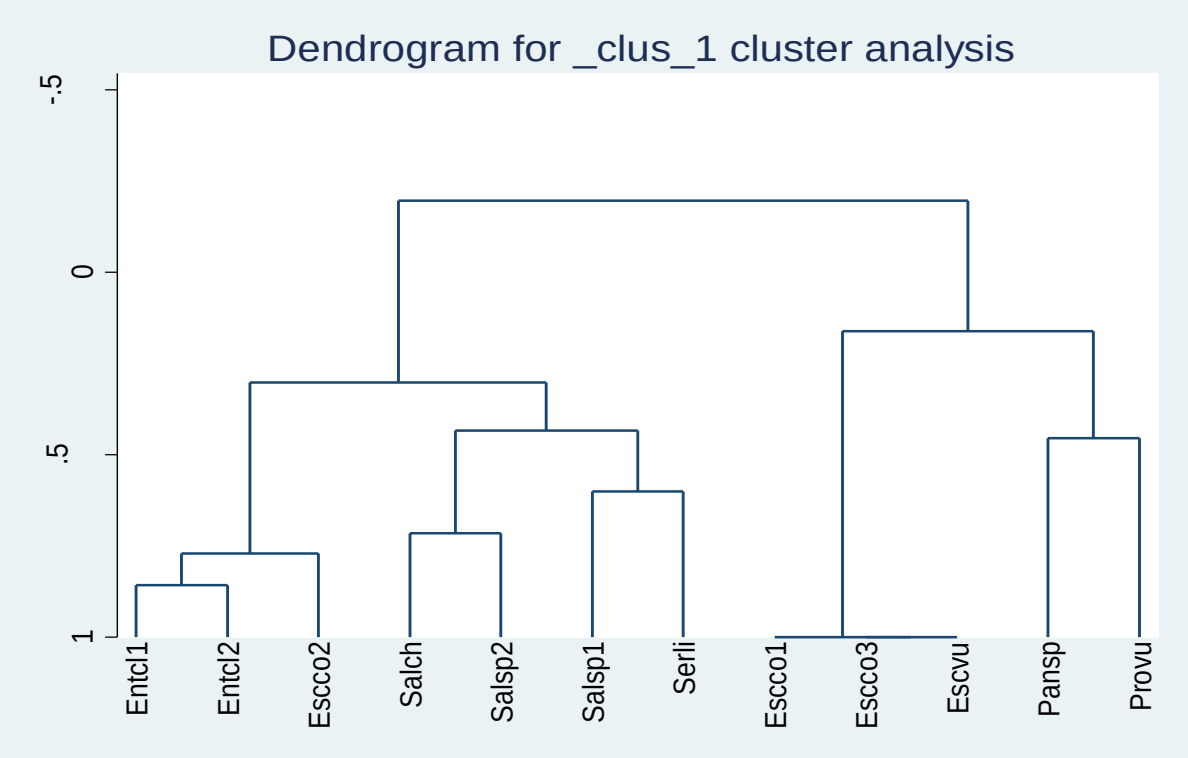

Figure 8. Dendrogram generated by hierarchical ascending classification of biochemical characteristics of enterobacteria strains identified in tomatoes; *Entcl: Enterobacter cloacae ; Escco : Escherichia coli, Escvu : Escherichia vulneris, Pansp : Pantoe spp 1, Provu: Providencia stuartii, Salch : Salmonella enterica ssp arizonae, Salsp: Salmonella spp, Serli : Serratia liquefaciens*

Discriminative Factorial Analysis (DFA) of the biochemical characteristics of these species enabled us to discriminate the three (3) on the basis of seven (7) biochemical characteristics (ADH, LDC, ODC, CIT, URE, VP, INO) (figure 9). Group 1 comprises strains with ADH (approx. 50%) and LDC (approx.

20%), and a few species with urease (URE+ approx. 30%). Group 2 is characterized by a total absence of these discriminating characteristics. The third group is characterized by the presence of ADH (50%) and urease (50%).

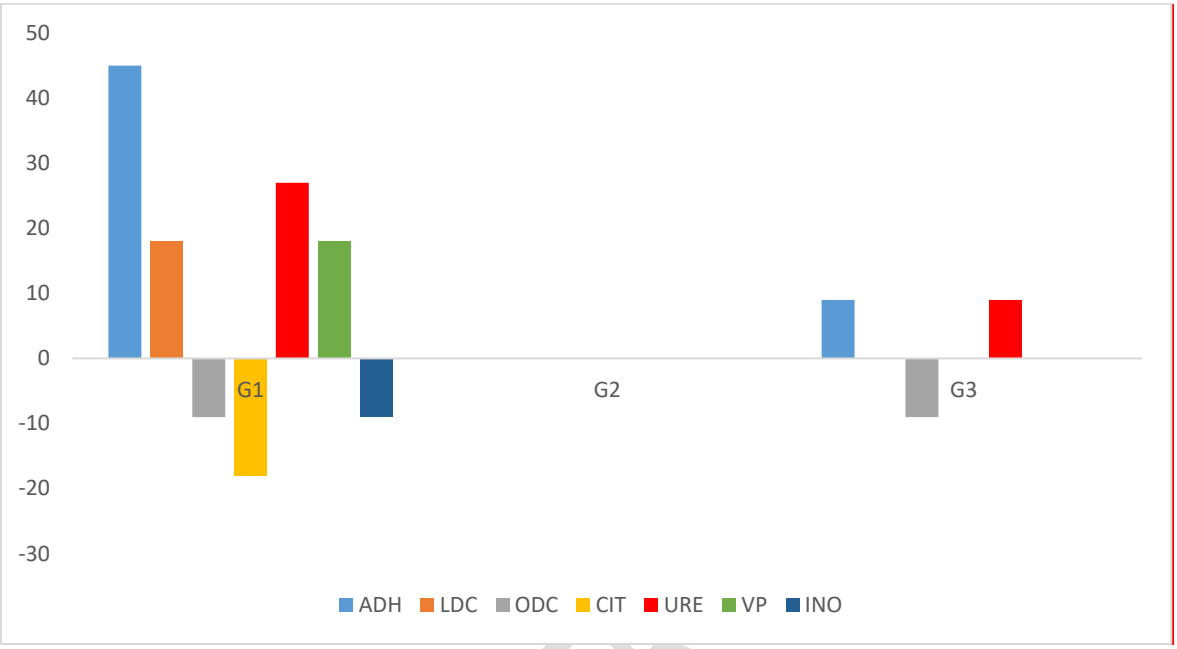

Figure 9. Graphical representation of discriminant function coefficients

The Correspondence Factorial Analysis (CFA) carried out between bacterial groups and the different bacterial species clearly shows the distribution of bacteria into three (3) groups (figure 10). Group 1 is made up of *Enterobacter cloacae, Salmonella enterica, Salmonella spp* and *Serratia liquefaciens*, and group 2 of *Escherichia coli* 2 and *Escherichia vulneris*. Both (2) groups share the *Escherichia coli*1 species in common, which was clearly demonstrated by the dendrogram that group 1 has an *Escherichia coli1* strain and so does group 2. The third group is made up of *Pantoea spp1* and *Providencia stuartii*

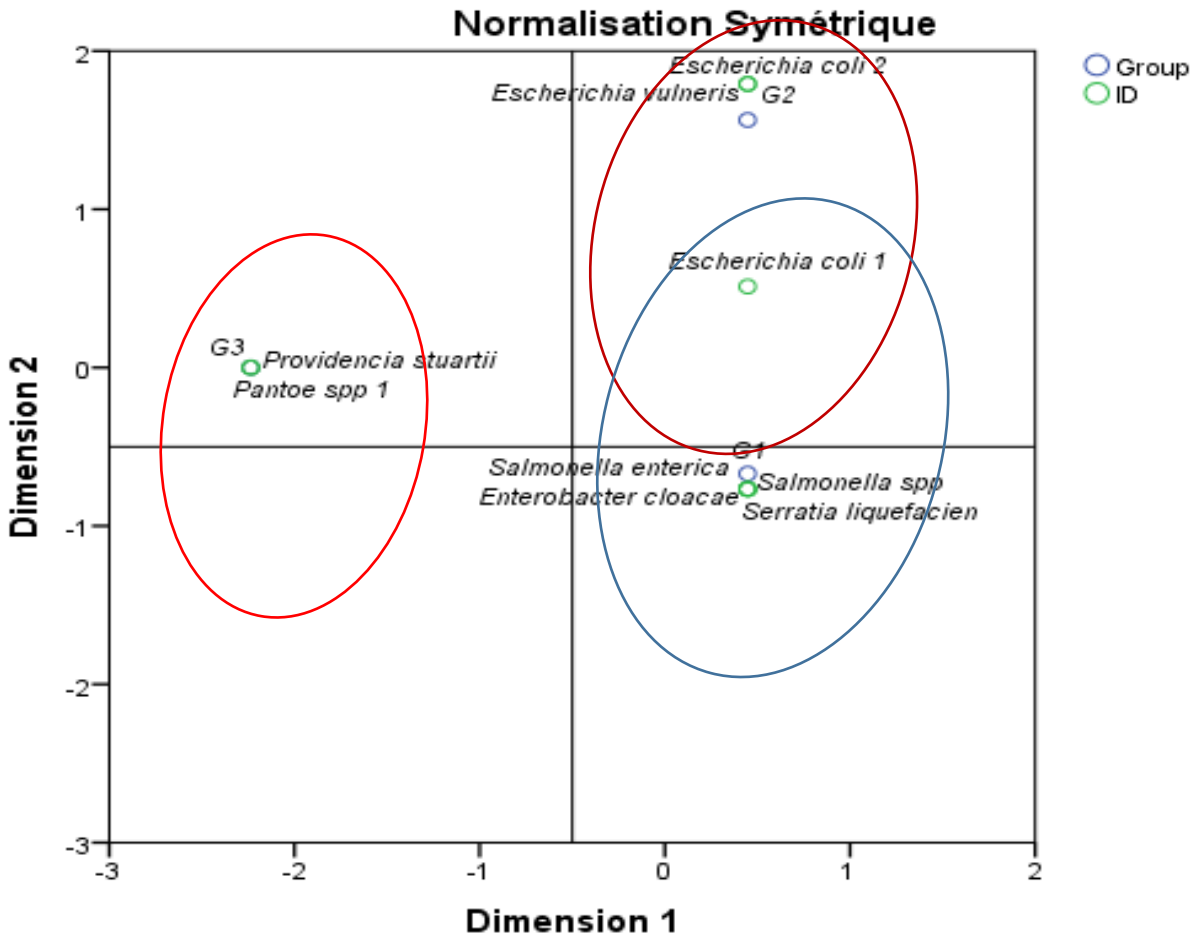

Figure 10. Projection of groups in the factorial axis system

Figure 11 shows the results of the CFA between the sampling sites and the bacterial species identified. Analysis of this figure shows that *Escherichia coli2, Escherichia vulneris* and *Providencia stuartii* are well represented at the market garden site (field), while *Pantoea spp*1 and *Serratia liquefaciens* are well represented at market 1. *Salmonella enterica* was observed at market 5. However, *Escherichia coli1* strains are distributed between the field and market 2, and *Enterobacter cloacae* strains between markets 1 and 2. *Salmonella* spp. are present in markets 2 and 3.

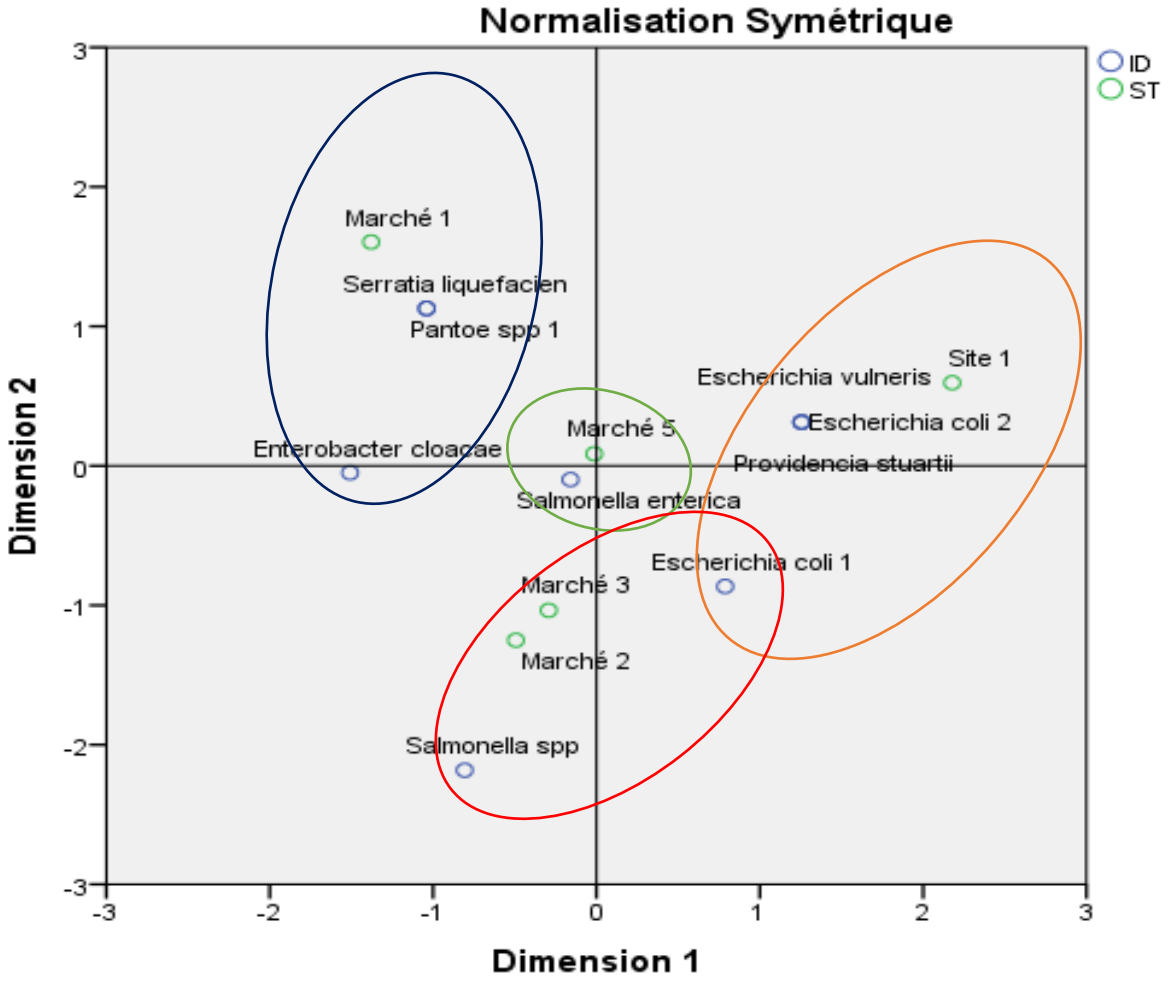

Figure 11. Projection of the spatial distribution of the different species identified in the factorial plane

3. DISCUSSION

This study assessed the microbiological quality of tomato samples taken from five (5) markets and one market garden in the urban community of Niamey. This assessment was carried out by looking for contamination indicators (total aerobic mesophilic flora (FAMT), total coliforms (TC), faecal coliforms (FC), enterobacteria (Ent), faecal streptococci (FS), *Clostridium perfringens (CP)* and *Escherichia coli (E. coli)*) and identifying a few species of enterobacteria.

FMAT gives an indication of the degree of general contamination of the food, which is a prerequisite for its acceptability for consumption. It is also known as food spoilage flora (Kasse *et al*., 2014, Almou *et al*., 2024). The study revealed the presence of FAMT in tomato samples. The loads obtained were high, mostly exceeding the microbiological criteria defined by AFNOR (1996). Only one market was found to be of satisfactory microbiological quality (Market 1). The total coliform and fecal coliform loads are all above microbiological criteria. Total coliform counts range from 5.11 Log10 CFU/g tomato (Market 1) to

5.75 Log10 CFU/g tomato (Market 5). Fecal coliforms ranged from 4.95 Log10 CFU/g of tomato to 5.57 Log10 CFU/g of tomato (market 5). A similar finding was made in Nigeria by Shenge *et al*. (2015). These authors reported a high level of contamination of tomato market samples with total coliforms (around 5.4 Log10 CFU/g tomato). In Côte d'Ivoire, high loads of fecal coliforms were recorded in fruit, onion and tomato purée, with values ranging from $9.1x10^2$ to $1.3x10^4$ CFU/g (Anin *et al*., 2016 ; Almou *et al*., 2024). Total and faecal coliforms give an idea of the hygiene conditions during product manufacture and storage. They are indicators of processing and environmental hygiene. The enterobacteria to which coliforms belong also contain pathogenic strains, dangerous to consumers. They are indicators of faecal contamination, providing a more complete picture of potentially pathogenic germs (Anonyme, 2007 ; Wognin, 2014, Almou *et al.,* 2024) and, as such, are indicators of food safety (absence of danger) (Kasse *et al*., 2014). The results show very high enterobacteria loads for all the samples analyzed. These loads ranged from 5.35 Log10 CFU/g (market 1) to 6.31 Log10 CFU/g (market 4) for carrot. A similar observation was reported from Abidjan in Ivory coast (Wognin, 2014). The presence of bacteria of enteric origin in lettuces suggests a lack of good hygiene practices and fecal contamination that could be harmful when these vegetables are eaten raw (Wognin *et al*., 2022, Almou *et al*., 2024). Fecal Streptococcus loads are also very high, at around 5.99 Log10 CFU/g of tomato. *Clostridium perfringens* were absent in samples from certain markets (markets 2; 3; 4). *Escherichia coli* is a coliform that indicates fecal contamination of human origin, and therefore bears witness to the processor's hygiene. It also provides an indication of the presence of possible enteropathogenic strains (Kasse *et al*. 2014, Almou *et al*., 2024). *E. coli* loads ranged from 2.11 Log10 CFU/g tomato (market 1) to 5.35 Log10 CFU/g tomato (market 5). These results corroborate those obtained in samples of vegetables sold in Abidjan markets (Toe *et al.*, 2017). Several authors have made similar findings on other types of food including: mango slices sold in Dakar (Kasse *et al*., 2014) 4th range products (Anin *et al.,* 2016) and "Garba" samples (Anoman *et al*., 2018) sold in Abidjan markets and in kilichi samples (Almou, 2021). Of all the markets studied, samples from market 1 were more contaminated than the others. This high level of contamination could be explained by the location of vegetable vendors inside the market. These vendors display their vegetables along the roadside, with wastewater poured directly onto the road. However, samples from the field are also highly loaded with the various contamination indicators we're looking for. Compared with contamination levels observed in the markets, samples from the field are less contaminated, with the exception of market 1, where the average load of FAMT in the market is higher than in the field. A similar finding was made in Côte d'Ivoire by Toe *et al*. (2017). In Nigeria, Shenge *et al*. (2015) found average *E. coli* loads of 0.92 Log MPN/g in tomatoes from the field and 2.66 Log MPN/g in those from the market, with percentages of tomato of unsatisfactory microbiological quality of 17% (73/420) and 57% (231/406) respectively. These high levels of contamination could be explained by the poor practices observed. Vegetables are rinsed with water that generally comes from taps installed in public toilets. They are also sold mainly on the ground covered with bags at the roadside of markets and in an unsanitary environment characterized by the presence of anarchic garbage dumps, gutters and drains, which are also niches for pathogenic bacteria (Koffi-Nevry *et al*., 2011, Toe *et al*. 2017, Almou *et al*. 2023). Thus, the microbiological quality of food could be directly linked to the quality of the water used by vendors to prepare food. Access to a safe water supply could therefore improve food safety.

Similarly, a sanitary environment where street foods are prepared and sold would significantly affect their hygienic safety Vanselow *et al*., 2005 ; Anin *et al*., 2016). When transporting these vegetables from the field to the market, wholesalers and resellers pack lettuces in inappropriate net bags, sometimes in trays without covers. These poor practices are thought to increase bacterial loads on raw edible vegetables (Wognin, 2014). Human crowding in the market is a factor in the input of microorganisms and increases the level of contamination of raw edible vegetables (Ndiaye, 2009 ; Adjrah *et al*., 2011). In addition, numerous actions, including rinsing operations and failure to protect vegetables during sale, create favorable environments and opportunities for pathogenic microorganisms to multiply (Alvaro *et al*., 2009 ; Ameko *et al*., 2012). On the other hand, other authors have reported that vegetables from fields had significantly higher levels of contamination than vegetables from markets (Antwi-Agyei *et al*., 2015 ; Amoah *et al*., 2007). They explained this difference by the fact that, the handling practices and sanitary conditions after harvest and during marketing that they had to observe in their study did not increase the initial contamination levels of vegetables in markets (Toe *et al*., 2017).

Moreover, twelve (12) strains of enterobacteria, divided into 9 species belonging to six (6) genera, were also identified. The species identified were *Enterobacter cloacae, Escherichia coli* 1 and 2, *Escherichia vulneris, Pantoea spp1, Providencia stuartii, Salmonella enterica, Salmonella* spp and *Serratia liquefaciens*. Hierarchical Ascending Classification (HAC) of the biochemical characteristics of the identified enterobacteria strains based on Jaccard's index using Ward's method identified three (3) groups. A Discriminative Factorial Analysis (DFA) of the biochemical characteristics of these species enabled us to discriminate the three (3) groups on the basis of seven (7) biochemical characteristics (ADH, LDC, ODC, CIT, URE, VP, INO). Then, the Corresponding Factor Analysis (CFA) performed between the bacterial groups and the different bacterial species clearly shows the distribution of bacteria into three (3) groups.

CONCLUSION

An assessment of the level of bacteriological contamination in tomatoes produced and sold in Niamey shows that the loads of contamination indicators are well above the standards recommended by the Association Française de Normalisation (AFNOR) for vegetables. These results suggest that the consumption of these tomatoes without any hygienic precautions could present a health risk for the consumer. The fact that these tomatoes are eaten raw increases the risk of transmitting infectious diseases such as cholera, typhoid fever, gastroenteritis, etc. It is therefore imperative to learn how to handle them properly. It is therefore imperative to train and raise awareness among vegetable producers and sellers of the rules and good hygiene practices involved in the production and marketing of vegetables. To gain a better understanding of this contamination, it will be important to determine the antibiotic resistance profiles and genes of these pathogenic *Enterobacteriaceae* species in these products.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

CONSENT

The vegetable samples were collected during the survey at the market garden sites and vegetable sales markets. All the market gardeners and vegetable sellers freely agreed, collaborated and gave their consent for the collection of the vegetable samples. The international standards were used for sample analysis.

AVAILABILITY OF DATA AND MATERIALS

The data that support the findings of this study are available from the corresponding author.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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