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(RESEARCH ARTICLE)

Study of biochemical parameters in farmers exposed to pesticides used in cotton growing around the Bala hippopotamus pond

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Abstract

Repeated exposure to pesticides can cause a variety of human health problems, particularly among farmers. This work consisted in studying biochemical parameters and their evolution in cotton farmers exposed to pesticides.

A longitudinal study was conducted during and after the 2018/2019 cotton season on a cohort of cotton farmers around the Bala hippopotamus pond in the department of Satiri. Biochemical parameters were measured during and after the crop year on the Architect ci 4100.

The majority of the farmers had high uric acid (UA) and low blood sugar (Gluc) concentrations. A few had concentrations of Cholinesterase (ChE) (6.19%); Direct Bilirubin (BilD) (23.01%); Gamma Glutamyl Transferase (GGT) (8.85%); Alkaline Phosphatase (ALkP) (4.42%); Cholesterol (Chol) (4.42%); triglycerides (Trig) (4.42%); aspartate aminotransferase (AST) (4.42%) higher than normal and lower than normal albumin (Alb) (13.27%) and total protein (TP) (13.27%) concentrations. Analysis of the evolution of biochemical parameters showed that none of the producers had higher than normal ChE and TP concentrations. After the campaign, the number of producers with lower than normal values increased for AST, AlkP, Alb and Urea while those with higher than normal values increased for GGT, UA, Gluc, Chol, Trig and BilD. Also, a significant decrease in AST, ALT and creatinine (CreaC) concentrations and a significant increase in GGT and BilD concentrations were observed.

The existence of some disturbances of biochemical parameters in farmers should encourage to test the hypothesis of a link between pesticide exposure and the appearance of biochemical disorders in clinical trials.

Keywords: Pesticides; Farmers; Biochemical parameters.

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1. Introduction

Chemical pesticides are widely used in cotton cultivation to control pests. However, because of their nature, their physico-chemical, biochemical and toxicological properties, these molecules pose major risks to human health [1] and the environment [2]. In addition to accidental or voluntary acute poisoning, repeated exposure to pesticides can cause various human health disorders: neurological disorders [3, 4], endocrine disruption, leukemia, reproductive disorders [5, 6].

In Burkina Faso, most of the studies on health risks related to pesticide use have been conducted on the basis of cross-sectional surveys in agricultural areas [7]. Cases of intoxication linked to work accidents, the use of unauthorized pesticides and the conditions of application, poor management of pesticide remains and packaging, illiteracy of farmers and pesticide dealers, environmental contamination; etc., have been reported to draw the attention of stakeholders to the human health problems that could result from the professional use of pesticides. Other studies have assessed the risk of operator exposure through modeling [8, 9].

Moreover, very few studies exist concerning the analysis of biomarkers of pesticide exposure and effect and their evolution within the same farmer population in Burkina Faso. Rare studies such as those in Toé et al.; [10] and Ouedraogo et al.; [9] respectively on insecticide applicators and sugarcane workers, are referenced. The first author showed that the prevalence of biochemical alterations seemed to be related to the frequency of pesticide use, before suggesting more in-depth studies.

Biomarkers of effect are important for documenting preclinical alterations [11] or adverse health effects induced by external exposure and absorption of a compound [12] such as a pesticide. Among biomarkers, biochemicals are more or less specific and frequently used to assess intoxications and to show the disruption of organ function by certain families of pesticides. For example, the change in cholinesterase (ChE) activity after exposure to organophosphate insecticides is an example of a specific indicator [13]. Several other additional biochemical parameters present in human biological fluids have been used as biomarkers to detect early effects of pesticides. Studies on the human toxicity of pesticides have also focused on biological parameters related to organ function. For example, altered activities of liver enzymes, such as alanine aminotransferase (ALT) and aspartate aminotransferase (AST), have been reported in pesticide workers exposed to organophosphates [14, 15, 16, 17, 18, 19].

In practice, the control and monitoring of pesticide exposures is mainly suggested by the established concept of reference value and associated analytical procedures. This concept is an essential contribution to an objective discussion of risk with respect to individual stress and strain profiles in environmental exposure scenarios [20].

For this study, the organic analysis involved conventional cotton growers who use pesticides to control pests. Knowledge of biochemical disturbances and parameter changes was considered as one of the necessary steps to understand the risk related to farmers' exposure to pesticides.

2. Material and methods

2.1. Site and type of study

The department of Satiri served as the study area. It is located in the southern cotton zone of SOFITEX about 40 km from Bobo-Dioulasso. This zone is characterized by intensive production of conventional cotton. The transition to exclusive conventional cultivation in 2016 will mean that producers will have to handle a high level of pesticides. The study was conducted among cotton producers located around the Bala hippopotamus pond biosphere reserve in three villages (Bala, Tiarako and Sokourani) bordering the reserve (figure 1). This cross-sectional descriptive study was conducted during and six months after the 2018-2019 cotton season.

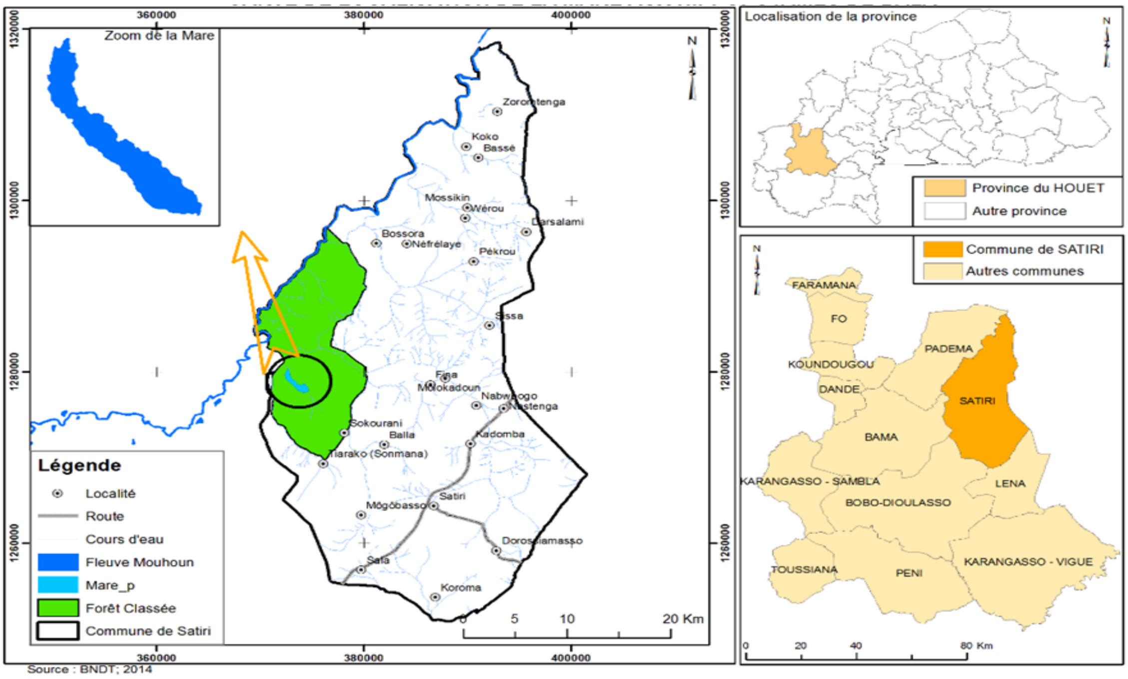

Figure 1: location of the study site

2.2. Population and sampling

The study concerned agricultural producers in the cotton basin around the Bala hippopotamus pond. These producers were included on the basis of their continued use of pesticides in cotton cultivation over the last 5 years, their membership in the producer groups (GPC) of the three villages and their actual handling of pesticides during the 2018-2019 season. A preliminary survey was conducted to determine the socio-demographic and health characteristics and the pesticides used by the farmers. Producers who reported fasting and who did not have a medical history were sampled. To see the evolution of biochemical parameters, the two lists of producers concerned by the sampling during and six months after the cotton season were crossed and 33 producers were included in the comparison. The sample considered during the cropping period was 113 farmers.

2.3. Collection and processing of blood samples

After a preliminary investigation (medical examination and pesticides used), the selected producers had blood samples taken during and six months after the cotton season. A venipuncture was carried out using a needle with a vacutainer support. Three (03) ml of whole blood was taken from the fold of the elbow. This entire operation was carried out under strict aseptic conditions. The blood was then packaged in a dry tube and transported directly to the laboratory in coolers containing the tube racks. At the laboratory, the blood samples were centrifuged. The obtained serum is aliquoted, and stored at a temperature of -20°C prior to analysis.

2.4. Analysis of biochemical parameters

The methods/principles and reference intervals for the analysis of the various biochemical parameters on Architect ci4100 are given in Table 1. Architect ci4100 is a biochemical automaton with two analysis modules. A chemistry module, the c4000 and an immunology module, the i1000SR. The c4000 uses two principles. One is photometry, a technique used on the C analyzer for measuring the absorbance of the sample, which allows the concentration of the substance being analyzed to be quantified. It concerns most analyses. The other is indirect potentiometry used for electrolytes such as Na, K and Cl [21].

Table 1 List of biochemical parameters, methods of analysis and reference intervals

Biochemical parameters	Methods and principles of analysis on Architect	Reference intervals
Cholinesterase (ChE)	Enzymatic	4389-10928 (U/L)
Acid Phosphatase (ACP)	Enzymatic	0-6 U/L
Aspartate amino Transferase (AST)	Immunological by chemiluminescence	5-34 U/L
Alanine amino Transferase (ALT)	Immunological by chemiluminescence	0-55 U/L
Gamma glutamine transferase (GGT)	Enzymatic	9-64 U/L
Alkaline phosphatase (AlkP)	Enzymatic	40-150 U/L
Direct Bilirubin (BilD)	Diazoreaction	0-8.6 μmol/L
Total Proteins (TP)	Biuret Method	64-83 g/L
Albumin (Alb)	Colorimetry	35-50 g/L
Cholesterol (Chol)	Enzymatic	0-5.17 mmol/L
Triglycerides (Trig)	Immunological by chemiluminescence	0-1.69 mmol/L
Urea (Urea)	Immunological by chemiluminescence	2.5-9.2 mmol/L
Creatinine C (Crea-C)	Alkali picrate kinetics	50.4-110.5 μmol/L
Uric acid (UA)	Immunological by chemiluminescence	150-350 μmol/L
Amylase (Amy)	Enzymatic	25-125 U/L
Glucose (Gluc)	Hexokinase method	3.89-5.50 mmol/L

2.5. Data analysis

The data were entered using the Excel 2016 spreadsheet and analyzed using XLSTAT 2014 software. The results were given in the form of descriptive statistics (mean, minimum, maximum, standard deviation). The Pearson correlation test was used to compare the data of the two phases. The differences were significant for an error probability value lower than 5%.

2.6. Ethical considerations

The study protocol was submitted and obtained the favorable opinion of the Ethics Committee for Health Research (CERS) of Burkina Faso, deliberation n ° 2018-7-083.

3. Results

3.1. Socio-demographic characteristics of the study population.

The farmers surveyed were all male with a median age of 36 years with extremes ranging from 17 to 69 years. The socio-demographic characteristics of the population are given in Table 2.

Table 2 Socio-demographic characteristics of farmers

Sex	
Male	100 %
Female	0 %
Age group	
[15-30[	35.40 %
[30-45[	34.51%
[45-60[	28.32%
[60-75[	1.77%
Median	36 age
Mean ± standard deviation	36.58±12.06
Education	
Illiterate	60.18%
Primary level	19.47%
Secondary level	19.47%
Higher level (Bac +)	0%

3.2. Pesticides used by farmers

The preliminary survey identified the different pesticides used during the agricultural season by farmers. The characteristic list of these is given in Table 3.

Table 3 Characteristics of pesticides reported among farmers

Commercial product	**Pesticide type**	**WHO Toxicity**	**WHO Registration status**	**Active substances**	**Active substance groups**	**WHO Toxicity**
ACERO 84 EC	I	II	Yes	Isoclast (sulfoxaflor)	Sulfoximine	III
				Lambda-cyhalothrin	Pyrethroid	II
ACTION 80 DF	H	III	Yes	Diuron	Phenylamide	III
ADWUMA WURA	H	U	No	Glyphosate	Phosphonoglycin	III
AVAUNT 150 EC	I	III	Yes	Indoxacarb	Oxadiazine	II
DIGA-FAGALAN 360 SL	H	III	Yes	Glyphosate	Phosphonoglycin	III
DIURALM 80 WG	H	III	Yes	Diuron	Phenylamide	III
EMAPYR	I	III	Yes	Emamectin benzoate	Derived from microorganisms	II
				Pyriproxyfen	Pyridine derived	U
GALLANT SUPER	H	III	Yes	Haloxyfop-p-methyl	Aryloxyphenoxypropionate	II

GLYCEL 410 SL	H	II	Yes	Glyphosate	Phosphonoglycin	III
GLYPHADER 75 SG	H	III	Yes	Glyphosate	Phosphonoglycin	III
GLYPHADER 360 SL	H	U	Yes	Glyphosate	Phosphonoglycin	III
GLYPHE	H	U	Yes	Glyphosate	Phosphonoglycin	III
GLYPHOBAR 480 SL	H	III	Yes	Glyphosate, isopropylamine salt	Phosphonoglycin	III
GRAMOSHAP SUPER	H	II	No	Paraquat dichloride	Quaternary ammonium compound	II
HALONET 104 EC	H	III	Yes	Haloxyfop-p-methyl	Aryloxyphenoxypropionate	II
IMIDALM-T 450 WS	F	II	Yes	Imidacloprid	Neonicotinoid	II
				Thiram	Carbamate	II
KALACH 360 SL	H	III	Yes	Glyphosate	Phosphonoglycin	III
KILLER 450 SL	H	U	Yes	Glyphosate	Phosphonoglycin	III
LADABA	H	U	No	Glyphosate	Phosphonoglycin	III
LAMACHETTE 360 SL	H	III	Yes	Glyphosate	Phosphonoglycin	III
LIBERATOR 500 SC	H	III	Yes	Diflufenican	Carboxamide	III
				Flufenacet	Oxyacetamide	II
NICOMAIS 40 SC	H	III	Yes	Nicosulfuron	Sulfonylurea	U
POWER	H	III	Yes	Diuron	Phenylamide	III
PYRINEXQUICK 424 EC	I	II	Yes	Deltamethrin	Pyrethroid	II
				Chlorpyrifos-ethyl	Organophosphate	III
ROUNDUP 360 XL	H	III	Yes	Glyphosate	Phosphonoglycin	III
SEGAIBANA 40 SC	H	U	Yes	Nicosulfuron	Sulfonylurea	U
TIHAN175 O-TEQ	I	III	Yes	Spirotetremate	Tetramicacid	III
				Flubendiamide	Benzene-dicarboxamide	III

I: insecticide; H: herbicide; F: fungicide

3.3. Analysis of biochemical parameters during the exhibition

The average, maximum and minimum values of the concentrations of the different parameters of 113 farmers analysed during exposure period are given in Table 4. Table 5 summarizes the distribution of farmers according to the reference intervals of the parameters. During this period, some farmers had concentrations of BilD (23.01%); GGT (8.85%); AlkP (4.42%); Chol (4.42%); Trig (4.42%); AST (4.42%) above normal and concentrations of Alb (13.27%) and TP (13.27%) below normal. However, 23.01% of the producers had non-conjugated bilirubinemia and 7.07% had hepatocellular insufficiency. No increase in creatinine and urea concentrations was observed in the farmers. On the other hand, 13.27% and 2.65% of them showed respectively amylasemia and hyperglycaemia, while 5.30% showed both amylasemia and hyperglycaemia.

Table 4 Descriptive values of concentrations of biochemical parameters during the exposure phase.

Parameters	**ChE** (U/L)	**ACP** (U/L)	**ALT** (U/L)	**AST** (U/L)	**GGT** (U/L)	**AlkP** (U/L)	**Alb** (g/L)	**TP** (g/L)	**Urea** (mmol/L)
Minimum	164	0	5	3	4	17	4	8	2
Maximum	13340.9	3.5	95	99	166	275	64	97	7,4
Mean ± standard deviation	6951.7±2761.41	1.2±0.93	9.29±8.83	21.12±10.35	35.46±25.42	66.37±32.21	40.72±13.66	74.64±22.01	3.27±1.13
Parameters	**Creat** (μmol/L)	**UA** (μmol/L)	**Gluc** (mmol/L)		**Amy** (U/L)		**Chol** (mmol/L)	**Trig** (mmol/L)	**BilD** (μmol/L)
Minimum	42.6	60	0.28		3		0.17	0.08	1.8
Maximum	106.1	631.11	5.22		196		5.72	8.53	24
Mean ± standard deviation	71.82±12.39	365.61±94.25	2.69±1.04		87.44±39.26		3.40±0.98	0.85±0.84	7.39±4.28

Table 5 Distribution of farmers according to parameter reference intervals during the exposure period.

Parameters	**ChE** (U/L)			**ACP** (U/L)			**ALT** (U/L)			**AST** (U/L)		
reference Interval	<4389	4389 to10928	>10928	0	0 to 6	>6	<0	0 to 55	>55	<5	5 to 34	>34
Size	12	94	7	0	113	0	0	112	1	1	107	5
Frequency (%)	10.62	83.19	6.19	0	100	0		99.11	0.88	0.88	94.69	4.42
Parameters	**GGT** (U/L)			**AlkP** (U/L)			**Alb** (g/L)			**TP** (g/L)		
reference Interval	<9	9 to 64	>64	<40	40 to 150	>150	<35	35 to 50	>50	<64	64 to 83	>83
Size	10	93	10	7	101	5	15	91	7	15	55	43
Frequency (%)	8.85	82.30	8.85	6.19	89.38	4.42	13.27	80.53	6.19	13.27	48.67	38.05
Parameters	**Urea** (mmol/L)			**Creat** (μmol/L)			**UA** (μmol/L)			**Gluc** (μmol/L)		
reference Interval	<2.5	2.5 to 9.2	>9.2	<50.4	50.4 to 110.5	>110.5	<150	150 to 350	>350	<3.89	3.89 to 5.50	>5.50
Size	33	80	0	7	106	0	6	37	70	94	16	3
Frequency (%)	29.20	70.80	0	6.19	93.81	0	5.31	32.74	61.95	83.19	14.16	2.65
Parameters	**Amy** (U/L)			**Chol** (mmol/L)			**Trig** (mmol/L)			**Bild** (μmol/L)		
reference Interval	<25	25 to 125	>125	<0	0 to 5.17	>5.17	<0	0 to 1.69	>1.69	<0	0 to 8.6	>8.6
Size	7	91	15	0	108	5	0	108	5	0	87	26
Frequency (%)	6.19	83.53	13.27	0	95.58	4.42	0	95.58	4.42	0	76.99	23.01

Table 6 Distribution of farmers common to the two sampling phases according to the reference intervals

Parameters	**ChE** (U/L)			**ACP** (U/L)			**AST** (U/L)			**ALT** (U/L)			**GGT** (U/L)		
reference Interval	<4389	4389 to 10928	>10928	<0	0 to 6	>6	<5	5 to 34	>34	<0	0 to 55	>55	<9	9 to 64	>64
Size 1	2	28	3	0	33	0	0	31	2	0	32	1	3	27	3
Size 2	5	28	0	0	33	0	1	30	2	0	33	0	0	22	11
Frequency 1 (%)	6.06	84.85	9.09	0.00	100.00	0.00	0	93.94	6.06	0	96.97	3.03	9.09	81.82	9.09
Frequency 2(%)	15.15	84.85	0.00	0.00	100.00	0.00	3.03	90.91	6.06	0	100	0	0	66,67	33,33
Parameters	**AlkP** (U/L)			**Alb** (g/L)			**TP** (g/L)			**Urée** (mmol/L)			**Créat** (µmol/L)		
reference Interval	<40	40 to 150	>150	<35	35 to 50	>50	<64	64 to 83	>83	<2,5	2,5 to 9,2	>9,2	<50,4	50,4 to 110,5	>110,5
Size 1	4	29	0	3	28	2	1	20	12	5	28	0	1	32	0
Size 2	31	2	0	8	23	2	0	33	0	10	23	0	0	33	0
Frequency 1(%)	12.12	87.88	0.00	9.09	84.85	6.06	3.03	60.61	36.36	15.15	84.85	0.00	3.03	96.97	0.00
Frequency 2(%)	93.94	6.06	0.00	24.24	69.7	6.06	0.00	100.00	0.00	30.30	69.70	0.00	0.00	100.00	0.00
Parameters	**UA** (µmol/L)			**Gluc** (mmol/L)			**Chol** (mmol/L)			**Trig** (mmol/L)			**Bild** (µmol/L)		
reference Interval	<150	150 to 350	>350	<3.89	3.89 to 5.50	>5.50	<0	0 to 5.17	>5.17	<0	0 to 1.69	>1.69	<0	0 to 8.6	>8.6
Size 1	1	8	24	27	6	0	0	33	0	0	31	2	0	24	9
Size 2	0	6	27	6	17	10	0	31	2	0	25	8	0	17	16
Frequency 1(%)	3.03	24.24	72.73	81.82	18.18	0.00	0.00	100.00	0.00	0.00	93.94	6.06	0.00	72.73	27.27
Frequency 2(%)	0.00	18.18	81.82	18.18	51.52	30.30	0.00	93.94	6.06	0.00	75.76	24.24	0.00	51.52	48.48

Table 7 Comparison of parameter concentrations during and after exposure.

Parameters	**ChE** (U/L)	**ACP** (U/L)	**AST** (U/L)	**GGT** (U/L)	**AlkP** (U/L)	**Alb** (g/L)	**TP** (g/L)	**Urea** (mmol/L)
1st phase	7265.2±2564.20	1.0±0.87	21.50±3.76	40.5±30.68	54.8±13.29	41.3±12.34	79.6±14.23	3,6±1,03
2nd phase	6753.5±2746.60	0.5±0.41	14.3±9.22	63.0±67.07	25.5±6.88	41.1±12.40	71.8±3.53	3,7±1,44
Pvalue	**0.3947**	**0.9226**	**0.0039**	**< 0.0001**	**0.4047**	**0.3276**	**0.7057**	**0,2744**
Parameters	**Chol** (mmol/L)	**CreaC** (µmol/L)	**Gluc** (mmol/L)	**Trig** (mmol/L)	**UA** (µmol/L)	**BilD** (µmol/L)	**ALT** (U/L)	
1st phase	3.5±0.67	75.3±13.25	2.5 ±1.21	1.1± 1.39	386.6 ± 80.26	8.2 ± 5.26	8.2±3.79	
2nd phase	3.8±1.17	72.2±11.32	4.8±1.39	1.4±0.71	419.6±61.72	9.4 ± 4.62	6.6±4.42	
Pvalue	**0.4161**	**0.0056**	**0.5385**	**0.1619**	**0.0845**	**0.0209**	**< 0.0001**	

3.4. Evolution of concentrations of biochemical parameters during and after exposure

The results of the evolution of the parameters have been reported in Table 6. Thus, no farmers showed higher than normal concentrations of ChE and TP. Concentrations of AST, AlkP, Alb and Urea only decreased after the campaign. Also, an increase in concentrations of GGT, UA, Gluc, Chol, Trig and BilD was observed. A significant decrease in the concentrations of AST, ALT and CreaC followed by a significant increase in GGT and BilD was observed (Table 7).

4. Discussion

The survey showed that all the farmers were male. This male force is still today the main production force in intensive agriculture. Exposure of this important group to pesticides and related effects could ultimately be a handicap to sustainable agricultural productivity. Also, as several similar studies [22, 10] indicate, the illiteracy of the population (60.18%) would rather hinder the proper use of pesticides. Indeed, it is impossible in these conditions to read and understand the indications of good phytosanitary practices on labels.

Most producers have normal concentrations of biochemical parameters except for UA and Gluc for which the majority of producers have high and low concentrations respectively. Specifically, very few farmers (6.19%) showed intoxication with organophosphate and carbamate pesticides compared to the small number of farmers with high plasma cholinesterase levels. This seems justified by the number (only two pesticide specialties) and frequency of pesticide use by these families. Intoxication with these two chemical groups is linked to an inhibition of the activity of cholinesterase responsible for the catabolism of acetylcholine. However, the reversible effect was observed after the agricultural season when no individual had high cholinesterase levels. As for UA, one study tends to associate its increase in the occurrence of nephropathy in farmers and workers in sugar cane fields, who used pesticides for production [23]. Gaikwad et al. [24] also showed that the level of UA also increased in pesticide applicators, compared to a control group. According to Arrebola et al [25], organochlorine pesticides such as γ-HCH and o, p′-DDE have been associated with hyperuricemia. In *Clarias batrachus* fish, exposure to the pesticides carbaryl and phorate led to a significant increase in urea, uric acid and creatinine levels [26]. Overall, in a comparative exposed and unexposed study, the values of biochemical markers such as uric acid, urea, creatinine and AST were close to the upper limits of normal in agricultural producers exposed to pesticides [20].

With regard to glucose, a handful of farmers (2.65%) had hyperglycemia. Several studies have shown a significant association of many chemicals (organophosphate pesticides in particular) with hyperglycemia and diabetes [27, 28, 29, 30]. Individuals with albumin (13.27%) and TP (13.27%) concentrations lower than normal have been found. Although comparative studies are rare in humans to support these findings, Harabawy and Ibrahim [31] have shown similar trends in *Clarias gariepinus* fish exposed to carbofuran where significant decreases in TP and albumin were found. Patil et al. [19] also revealed significant increases in alkaline phosphatase and bilirubin in some farmers in grape fields. The pesticides used are quite different from those described in the present study, but the same trend is observed for alkaline phosphatases, which appear high during the exposure period compared to the period after exposure.

Some producers have cholesterol levels that are higher than normal. This is consistent with data from [32] who found in rats exposed to malathion and spinosad an increase in cholesterol levels and several other biochemical parameters such as ALT, AST, ALP and ACP. The increase in triglyceride levels in some individuals is supported by [33] as well as [14] in wistar rats exposed to malathion and in *Astacus leptodactylus* exposed to chlorpyrifos and glyphosate.

The evolution of the concentrations of biochemical parameters in the farmers showed a significant decrease in the concentrations of AST, ALT and creatinine and a significant increase in the concentrations of GGT. These observations were made by [34] on AST concentrations, through their study on the evaluation of the effects of agro-pesticide use on liver and kidney functions in Cameroonian farmers. They observed a significant increase in the activity of AST in farmers after comparison with the results of a reference population. On the other hand [14] showed a significant decrease in the activity of AST and a significant increase in GGT in *Astacus leptodactylus*.

The effect of pesticides on biochemical parameters appears to be related to study conditions such as the pesticide, the cocktail effect of pesticides, the exposed organism and the type of study.

5. Conclusion

The analysis of concentrations and changes in biochemical parameters of the effect of farmers' exposure to pesticides has yielded rather varied results. An increase in the concentrations of ChE, UA, BilD, GGT, ALP, Chol, Trig, AST and a decrease in those of Gluc, Alb, and TP were observed in some growers. In general, most farmers have normal concentrations of biochemical parameters except for UA and Gluc for which the majority of growers have high and low concentrations respectively. On the other hand, a significant decrease in AST, ALT and CreaC followed by an increase in GGT and BilD were observed. For a few rare parameters such as TP and albumin, pesticides can be at the origin of a decrease in concentrations. In general, there is also a tendency for concentrations of biochemical parameters to increase during exposure and a tendency to normalize about six (06) months after direct exposure. However, the exposed biological organism and the pesticide would be determining factors.

In order to further highlight the link between exposure to pesticide mixtures and the appearance of disorders of homeostasis of biochemical parameters, the present preliminary results could be supplemented by a follow-up study of the same group during exposure and non-exposure and then another group not directly exposed. This will make it possible to develop strategies for the management and prevention of pesticide-related health risks.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest was declared by any of the authors associated with this work.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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