SCIREA Journal of Economics
ISSN: 2995-3863
http://www.scirea.org/journal/Economics
June 4, 2024
Volume 9, Issue 2, April 2024
https://doi.org/10.54647/economics790457

Agromorphological and economic characterization of 09 accessions of tigernut (*Cyperus esculentus* L.) from the Sudano-Sahelian zone of Cameroon.

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Abstract

In order to enhance and improve the production of underutilized crops, a collection of the various tigernut accessions was carried out in the Kapsiki and Mafa production area of the Mayo-Tsanaga department. However, the lack of knowledge about the plant material used in the cultivation of tigernut (*Cyperus esculentus* L.) is an obstacle to the control of the cultivation practices of its production. Faced with this situation, a study of the characterization of 09 tigernut accessions was carried out under three different conditions of the production of this culture in order to describe certain qualitative and quantitative characteristics. To conduct these trials, the completely randomized design was used. The qualitative and quantitative parameters collected were analyzed with the XLSTAT software. The results show that, apart from the appearance of the tunic, which is identical in all tigernut accessions, all the other characters are different from each other. In addition, statistical analysis of the data by

Principal Component Analysis (PCA) showed that there are 04 distinct classes within the tigernut accessions tested. Only accessions C and E in classes 2 and 3 respectively showed high yield and profits compared to accessions in other classes. The better combination of the factors of production of the different tigernut accessions showed that it would be more profitable to produce with accessions A (*Glazay*) and E (*Wéchéché*) respectively because the marginal productivity of the products (reduced cost) is zero. Therefore, it is important to evaluate the types of fertilizers on tigernut accessions with high yield performance.

Keywords: Characterization, Accession, *Cyperus esculentus*, Yield, Sudano-Sahelian zone.

1. Introduction

Tigernut (*Cyperus esculentus* L.) has been domesticated and used as a food plant in almost every continent of the world (Africa, Southern Europe, Asia and North-East of the USA and Canada) (Dodet, 2008; Defelice, 2002; De Castro et al., 2015). It is deriving from the Mediterranean and East Asia (Shaker *et al.,* 2009). In developing countries, tigernut cultivation is a means of combating poverty and food insecurity, which remain major concerns of the international community today (Bori et al., 2018). In Niger, for example, the production and marketing of tigernuts provides substantial and significant revenues of around 452,461 CFA francs/ha to producers (Bori et al., 2018), which is close to an income of more than 500 million CFA francs/year for these producers (Houa et al., 2018). This income is used to meet the basic needs of rural households. Tigernut production is thus an alternative to rained crops, which have been subject to the problems of climatic disturbances in recent decades, which have aggravated soil degradation and thus jeopardize food production (Sakatai et al., 2020). This crop is well in line with the national strategies to improve food security in several countries, which are now moving towards the use of cultivation practices that preserve soil fertility, diversification and especially crop enhancement, with an emphasis on underutilized crops (secondary crops) which make a significant contribution to the economy of households in rural areas.

Alongside this improvement in producer's income, this plant is grown for its tubers, which have good nutritional value because they contain high amounts of fat, sugar, minerals and vitamins (Houa et al., 2018). Tigernut tubers are excellent sources of macronutrients (starch, fat and sugar) and minerals. Moreover, the proportions of proteins and minerals in tigernut tubers are higher than those of some basic foods (sorghum, maize, rice, etc.) consumed in

Africa (Ban-Koffi et al., 2005). In Benin, tigernut is one of the best-selling medicinal plants on the Abomey-Calavi market (Adamou et al., 2012). It is used to treat lethargy, indigestion, diarrhea, dysentery, sexual infertility (Adejuyitan, 2011). Tigernut due to its composition, provides proteins that are rich in essential amino acids such as lysine, threonine, leucine, phenylamine and cysteine (Agbaje et al., 2015). Furthermore, a traditional fermentation of tigernut can reduce the linoleic acid value by 0.65 to 0.57%, which is desirable in edible oils due to the bad tastes and potentially harmful oxidation products formed. Abireh et al. (2019) showed that tigernut helps prevent heart disease and thrombosis, allowing for proper blood circulation. Therefore, the treatment of urinary tract infections and other bacterial infections are also effective. It is also in relation to these multiple advantages that producers continue to domesticate this crop, which has nevertheless remained an "orphan crop" due to little work on its technical practice production.

In Cameroon, the mountainous areas of the Mayo-Sava and Mayo-Tsanaga departments are the main production areas of this crop, with about 27,000 tons/year on an area of 14,000 hectares (MINADER, 2009; Djomdi, 2014; Sakatai et al., 2020). The area sown for this crop is almost insignificant compared to other crops such as cereals and legumes.

Apart from the work of Sakatai et al. (2020); Djomdi, (2014) and Mbofung et al. (1997), tigernut cultivation has attracted very little scientific and technological attention in Cameroon, despite its economic, food and medicinal interest. However, it has interesting agronomic specificities due to its drought tolerance and is less demanding in terms of fertilizer (Sakatai et al., 2020). It is, therefore, an alternative means to combat the problems of climate change and variability that are increasingly felt in various localities in the northern part of Cameroon. This tigernut speculation deserves, in the same way as other crops, a scientific attraction in a dynamic of improving its production potential. It is with a view to improving tigernut production that this study on the agro-morphological and economic characterization of nine tigernut accessions was undertaken in the Sudano-Sahelian zone of Cameroon. The objective is to identify and characterize genotypes with good agronomic performance.

2. Methodology

2.1. Plant material

The plant material consisted of tigernut tubers (*Cyperus esculents* L.) collected from farmers and traders in the Far North region, Mayo-Tsanaga department. Thus, nine (09) accessions were collected before the rainy season. Each accession was identified by a code and characterized on the basis of similarities in tuber shape, size and color (Figure 1).

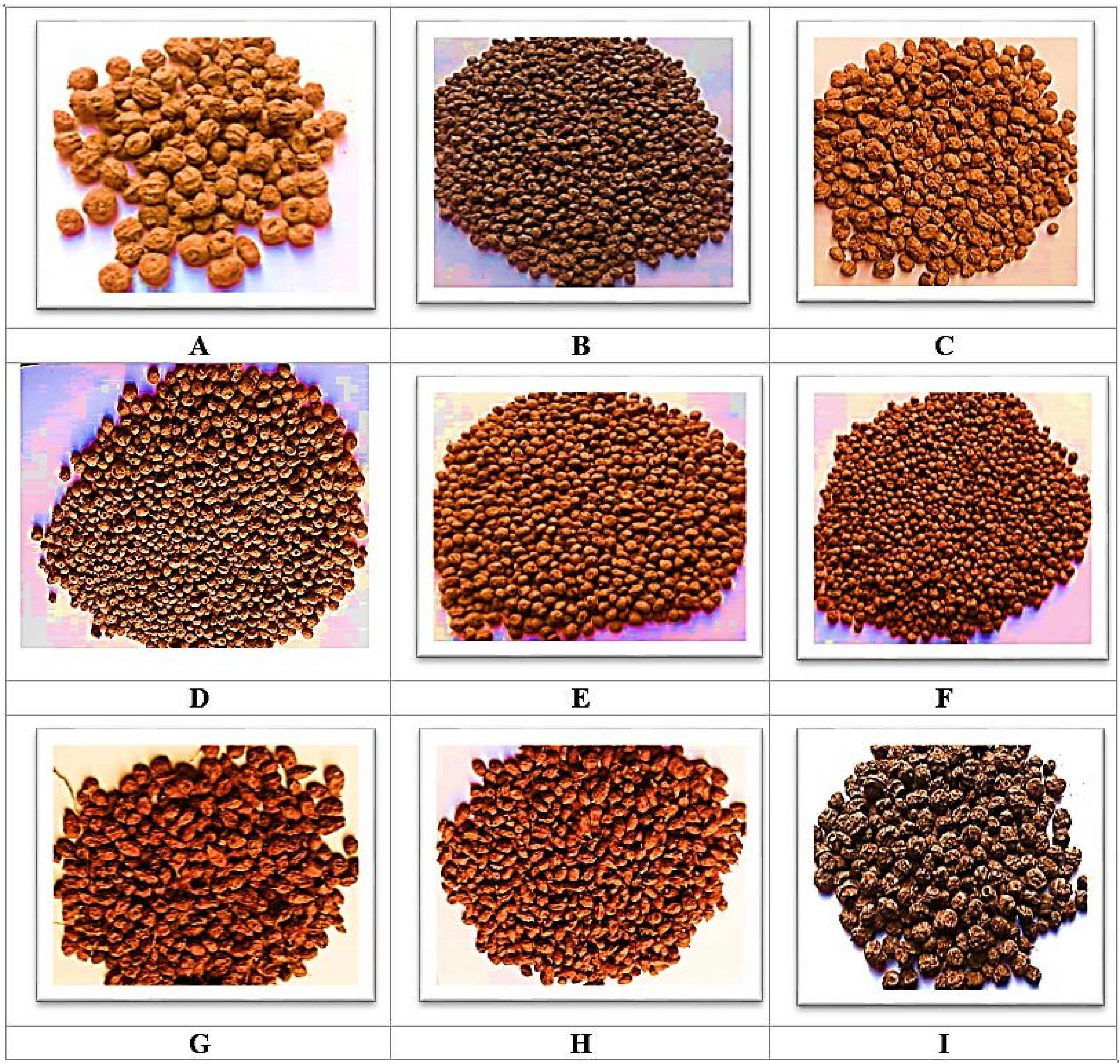

Figure 1: different tigernut accessions tested

2.2. Conduct of the test

The trial was conducted in a greenhouse station and in the field at the Meskine and Mandaka sites. At the station, the pots were prepared on May 23, 2022 and seeded with 10g of tigernut on May 24, 2022. In the field, the ploughing of the experimental plots was carried out on 20/07/2022 and 23/07/2022 respectively on the Meskine and Mandaka sites. These two sites differ in their topography. The Meskine site is located in the plain of the Diamaré department while the Mandaka site is located in the mountainous areas of the Mayo Tsanaga department.

The sowing of tigernut seeds in fields (350 kg/ha (Assétou, 2017)) was carried out on 25/07/2022 and 29/07/2022 respectively on the two sites. In all the trials conducted, seeding was broadcast according to the technical practice described by Sakatai et al. (2020). In the greenhouse at 15 days after sowing, NPK fertilizer (12-14-19) and ash were applied at a rate of 31g/pot and 30.21g/pot respectively. In addition, the application of NPK mineral fertilizer (12-14-19) at a rate of 250 kg/ha at the Meskine and Mandaka sites was carried out in the field. During the vegetative phase in the greenhouse, a daily supply of water was applied if necessary, whereas in the field, it was rainwater that irrigated the plots. For the duration of the trials, manual weeding was carried out in the field and in the pots. Images a, b, c and d show the different vegetative phases in the greenhouse and field in the tigernut. The harvest of tigernut tubers was carried out on 07/08/2022; 15/10/2022 and 17/10/2022 respectively in Greenhouse; Meskine and Mandaka.

a b c d

2.2.1. Data collection

The data consisted of observing agronomic and morphological parameters. Regarding growth and development parameters, 3 randomly marked plants per elementary plot were used as measurements each time. The yields in t/ha and the weight of 100 seeds were evaluated from the experimental units of each tigernut accession. The visual characterization of the qualitative parameters (leaf color, collar color) was done on the basis of the color chart (Mounsel's key). The dates of the cropping cycles (beginning tuber formation, beginning of maturation and floral appearance) were assessed using observable phenological stages. The prices of inputs, equipment and materials and, above all, the market value of outputs are assessed at the time of cultivation operations.

2.2.2. Data analysis

Once the data was collected, the principal component analysis (PCA) was performed to characterize the 09 accessions according to the parameters taken into account. The analysis of variance (Turkey test) was used to separate the mean values of some of the measured quantitative parameters. The assessment of the maximum economic per treatment is determined by equation (1). Yields in t/ha were extrapolated to tons per hectare and per treatment. Size, crown diameter, leaf length and width were converted and analyzed to the required units (mm and cm). The raw data were entered by the Microsoft Office EXCEEL 2013. Analyses of the variance of certain parameters were carried out by the XLSTAT software in order to see the variability (significance) in average yield (t/ha) of onion bulbs per treatment. The Microsoft Office EXCEEL 2013 made it possible to carry out the various operations relating to cost and benefit per treatment. The quantities of production inputs of the tubers with the best marginal productivity were evaluated using the GAMS 22.0 software. Linear Programming (PL) has made it possible to identify the best tigernut accession, which is associated with a type of fertilization, mineral fertilizer or ash. The following mathematical formulas were used for the optimization of all production inputs in order to estimate the best combination of inputs and one of the optimal profits from tigernut tuber production.

The production of 09 tigernut accessions was done in greenhouses (T_0) and on two study sites (T_1 and T_2). By cross-referencing the 09 accessions to the three conditions culture (T_0, T_1 and T_2), we obtain the activities of our linear programming problem which combines the modalities of the following factors (A, B, C, D, E, F, H, I) * (T_0, T_1, T_2)

The gross margin Cj is determined by:

$$\sum PiYiXi - \sum Ci \qquad (1)$$

For all i=1 to n; With Pi = the selling price in kg of tigernut tubers in CFA francs of each activity, Yi = yield of tigernut tubers in Kg of each activity, Xi = area in ha occupied by each activity of tuber production and Ci = total costs in CFA francs of production inputs invested in each activity of tuber production.

The function of objective Z to be maximized in this study is therefore formulated as follows:

$$\text{Maz } Z = C_j X_j = \sum_{j=1}^{9} \prod yj \, X \sum_{i=1}^{3} Ti \qquad (2)$$

Where Cj is the gross margin (in CFA franc /ha) of the activity produced (exogenous variable/data for the year calculated from equation (1). Where $\prod_j$ is the net gross surplus (in CFA francs/ha) of the activity produced (exogenous variable/data for the financial year calculated from equation (1). The endogenous variables to be estimated are of the order j, i and z such that XyjTi representing the areas (in ha) of the tigernut accessions to be produced according to each treatment applied where j and i respectively take the values of the corresponding intervals (j ∈ [1-9]; i ∈ [1-3]).

Tigernut production depended on major constraints such as fertilizer intensity. In addition, of course, there is the space that must be occupied by the various attachments of the tigernut, the labor for the cultivation operations, the cost of purchasing the seeds and the capital of the depreciation are the main (usual) factors of production. Thus, the function of the above objective will be maximized under the constraints of availability of land, labor, capital, depreciation and fertilizer according to the equations below:

Availability of capital for the rental of the plot (land): this equation states that the cumulative sum of the accessions of tigernut grown according to each study site and type of fertilizer is less than or equal to the capital available for the rental of the plot (C_{land}).

$$\sum_{j=1}^{9} Local, yj\, X \sum_{i=1}^{3} Ti \ \leq C_{land} \quad (3)$$

here Local, yjTi; ∀ j, i ε [1-9]; [1-3] These variables correspond respectively to the amounts of capital used for the lease/plot value of one ha to produce nutsedge tubers for a chosen activity.

Capital availability for depreciation; this equation stipulates that the sum of the capital shares per unit of each activity multiplied by the area of the activity must be less than or equal to the available capital (C_{amor}) for the depreciation of the planter's equipment and materials:

$$\sum_{j=1}^{9} AMORcap, yj\, X \sum_{i=1}^{3} Ti \leq \ C_{amor} \quad (4)$$

Where AMORcap, yjTi; ∀ j, i ε [1-9]; [1-3] respectively, this corresponds to the amounts of useful capital of depreciation to produce one ha of a chosen activity.

Availability for work; this equation stipulates that the summation of the shares of labor intensity in CFA francs per unit of each activity multiplied by the area of the activity must be less than or equal to the quantities of capital available (C_{labor}) by a planter:

$$\sum_{j=1}^{9} Labcap, yj\, X \sum_{i=1}^{3} Ti \ \leq C_{labor} \quad (5)$$

Where Labcap, yjEzTi; ∀ j, i ε [1-9]; [1-3] corresponds respectively to the quantities of capital required to produce one ha of tigernut by a given treatment.

Availability of capital for the purchase of fertilizers; this equation stipulates that the sum of the shares of capital per unit of each activity multiplied by the area of the activity must be less than or equal to the capital available (C_{elf}) for the purchase of fertilizer by a planter:

$$\sum_{j=1}^{9} ELFcap, yj\, X \sum_{i=1}^{3} Ti \ \leq C_{elf} \ldots \quad (6)$$

Where ELFcap, yjTi; ∀ j, i ε [1-9]; [1-3] corresponds respectively to the amounts of capital needed for the purchase of fertilizer to produce one ha with treatment.

Availability of capital for the purchase of seeds; this equation states that the sum of the shares of capital per unit of each activity multiplied by the area of the activity must be less than or equal to the available capital (C_{sem}) for the purchase of tigernut seeds by a planter:

$$\sum_{j=1}^{5} Scap, yj\, X \sum_{i=1}^{13} Ti \ \leq C_{sem} \ldots \quad (7)$$

Where Scap,yjTi; ∀ j, i ε[1-9]; [1-3] respectively, this corresponds to the amounts of capital useful for the purchase of accessions by a planter to produce on an area of one ha.

3. Results and Discussions

3.2. Characteristics of different tigernut accessions

Table 1 presents the qualitative morphological characteristics of different tigernut accessions tested under 03 different conditions of tigernut culture production.

Table 1: Qualitative morphological characteristics of different tigernut accessions

Nutsedge accessions	Leaf color	Leaf shape	General shape of the leaves	Leaf position	The appearance of the tunic	Collar color
Acc A	Dark green	Tapered	Trained	Superimposed	Pointed	White
Acc B	Lime green	Tapered	Untrained	Alternate	Pointed	Purple
Acc C	Light green	Wide	Trained	Superimposed	Pointed	Purple
Acc D	Lime green	Wide	Untrained	Alternate	Pointed	Purple
Acc E	Lime green	Tapered	Untrained	Alternate	Pointed	White
Acc F	Lime green	Tapered	Untrained	Alternate	Pointed	Purple
Acc G	Dark green	Wide	Trained	Alternate	Pointed	Purple
Acc H	Dark green	Wide	Trained	Alternate	Pointed	White
Acc I	Dark green	Wide	Trained	Alternate	Pointed	White

From all the qualitative observations made on all the different experimental media, the results reveal that, during the vegetative phase of tigernut (*Cyperus esculentus*) production, accession C showed a different leaf coloration (light green) than other tigernut accessions. Accessions B and F; H and I showed similar traits two by two depending on the parameters taken into account. Apart from the pointed tunic of the tigernut accessions, all other qualitative parameters are diversified between the tigernut accessions tested. As a result, 7 tigernut accession groups were formed according to the parameters taken into account. Principal Component Analysis (Discriminant Factor Analysis (DFA)) will better explain and predict the different accessions of tigernut in main normalization according to qualitative and quantitative morphological parameters. Figure 2 shows the distribution of the measured parameters around two normalization axes.

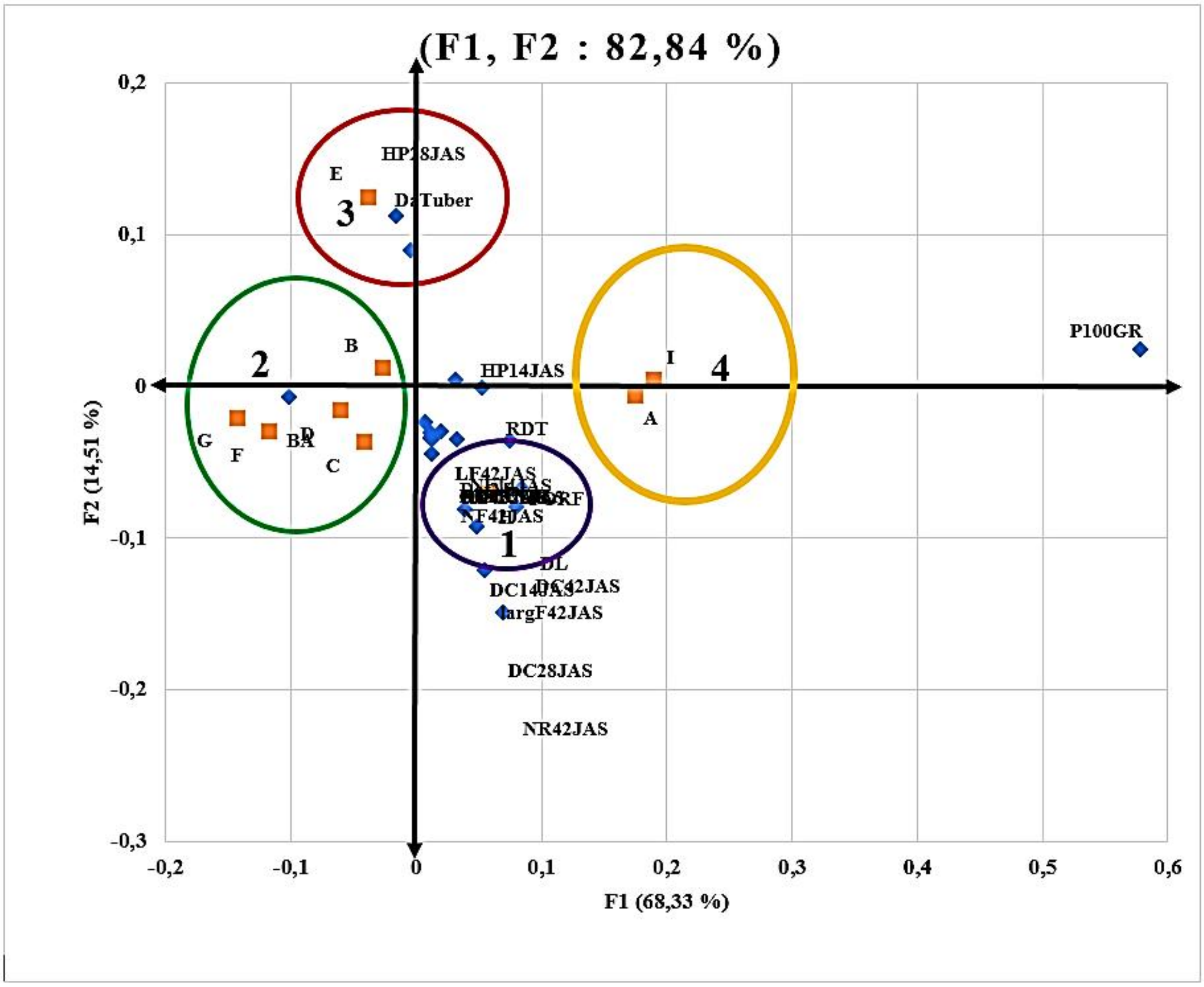

Figure 2: Standardization of qualitative and quantitative morphological parameters around two axes of normalization.

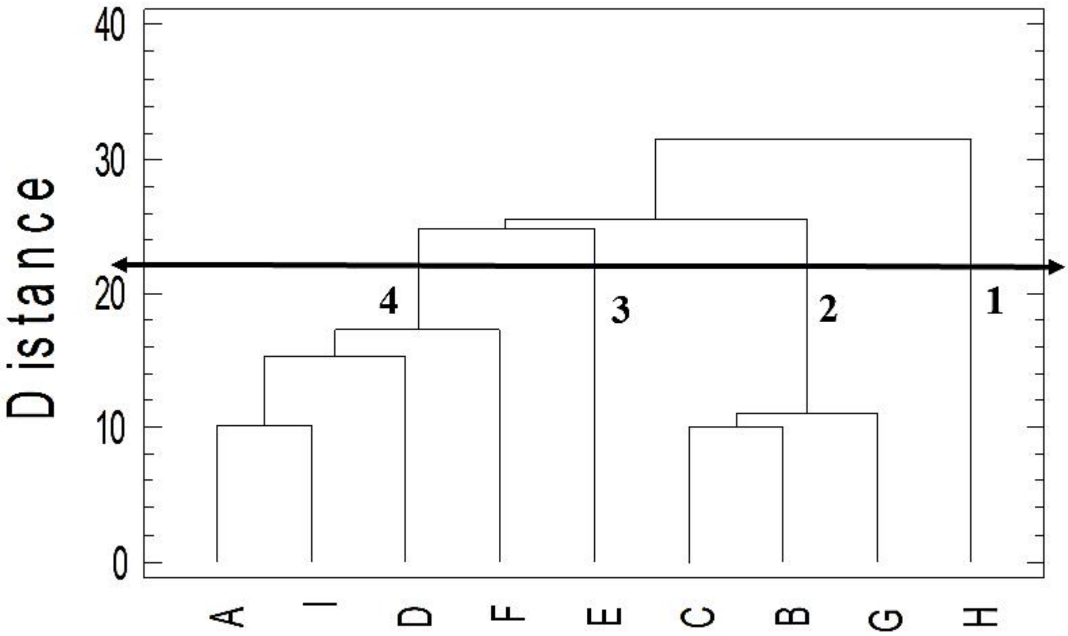

Figure 3: Dendrogram of the hierarchy of different accession of nutsedges tested

The outcome of figure 1 shows that 68.33% variability in the weights of the measured parameters is explained by dimension 1 of the normalization. And a total of 82.84% degree of the total variability of qualitative and quantitative morphological parameters is explained by the two dimensions of the main normalization. The distribution of tigernut accessions around these two axes showed four distinct classes. Class 1 consisting of accessions A, H and I; class 2 consists mainly of accession E and finally class 3 is composed of accessions B, C, D, G and F. The group of accessions constituted would have a similarity from the point of view of certain quantitative and qualitative morphological parameters considered.

3.3. Growth and Development parameters of tigernut accessions

Table 2 shows the mean values of height, crown diameter, number of leaves, leaf length and width, and number of branches at 42 days post-sowing of the different accessions according to the different condition culture production. The results of the analysis of variance in table 2 showed significant differences ($p \geq 0.005$; $p \geq 0.020$ and $p \geq 0.010$) at the 5% significance in terms of crown diameter, height and number of leaves from differences in nutsedge accessions at 42 days after sowing. At this vegetative stage, the largest values in crown diameter were obtained respectively with accessions A and I (7.94±1.75mm; 6.19±2.72mm), while the maximum size can reach 85.22±9.11 cm for a maximum total number of 12.00 leaves always with accession A.

Table 2: Mean values of selected growth parameters and development of accessions according to experimental environments

Measured Parameters	Experiments sites	Acc A	Acc B	Acc C	Acc D	Acc E	Acc F	Acc G	Acc H	Acc I	p (sig)
DC42JAS	Mokolo	5,16± 0,54	4,41± 0,68	3,70± 1,12	4,63± 1,06	3,67± 0,43	4,36± 1,24	4,09± 0,67	4,94± 1,07	5,26± 1,50	0,436
	Meskine	4,51± 0,43	5,14± 1,05	5,28± 1,08	4,08± 0,50	4,05± 0,90	4,70± 0,91	3,95± 0,99	3,84± 0,07	5,18± 1,42	0,480
	Serre	7,94±1,75c	3,33±,41a	4,61±1,35ab	2,99±,72a	3,61±,75a	3,86±91a	5,01±1,56ab	5,01±1,62ab	6,19±2,72bc	0,005
HP42JAS	Mokolo	66,77± 9,89	66,44± 4,34	66,66± 5,49	78,33± 4,58	64,89± 5,57	60,33± 6,01	69,44± 6,27	67,77± 6,76	68,89± 7,34	0,179
	Meskine	79,11± 16,45	74,22± 7,188	72,77± 0,50	73,44± 2,98	71,88± 3,35	65,00± 5,50	74,55± 8,37	56,77± 2,76	64,55± 2,69	0,317
	Serre	85,22±9,11c	68,33±6,59a	71,33±7,00ab	71,78±9,31ab	72,22±8,40ab	71,89±9,62ab	82,78±8,26bc	74,89±8,48abc	74,78±12,71abc	0,020
NF42JAS	Mokolo	11,00 ± 0,87	11,00 ± 0,38	11,00 ± 0,83	12,00 ± 1,07	11,00 ± 0,57	11,00 ± 0,19	11,00 ± 0,19	11,00± 1,00	11,00 ± 0,38	0,547
	Meskine	11,00 ± 1,64	12,00 ± 1,00	11,00 ± 2,26	12,00 ± 0,19	11,00 ± 1,07	11,00 ± 0,57	11,00 ± 0,50	10,00± 1,00	12,00 ± 0,57	0,449
	Serre	12,00 ±1,39b	8,00 ±1,86a	10,00±3,46ab	8,00 ±1,56a	9,00 ±2,00a	9,00 ±3,16ab	10,00 ±1,86ab	9,00 ±2,00ab	10,00±3,46ab	0,010
NR42JAS	Mokolo	2,00 ± 0,19	2,00± 0,33	2,00 ± 0,69	2,00 ± 0,69	1,00 ± 0,83	3,00 ± 0,83	1,00 ± 0,66	2,00± 1,00	2,00 ± 0,19	0,113
	Meskine	0,00 ± 0,00	1,00 ± 0,38	1,00 ± 0,69	1,00 ± 0,19	2,00 ± 0,33	0,00 ± 0,00	1,00 ± 0,00	1,00 ± 0,05	2,00 ± 1,07	0,277
	Serre	1,00 ± 0,00	0,00 ± 0,00	3,00 ± 1,00	1,00 ± 0,00	1,00 ± 0,00	1,00 ± 0,00	1,00 ± 0,00	2,00 ± 1,00	3,00 ± 1,00	0,590
LF42JAS	Mokolo	72,33± 8,14	72,00± 4,35	73,00± 10,44	80,00± 4,58	73,66± 11,06	68,00± 15,09	75,00± 9,53	71,33± 5,68	74,66± 10,59	0,931
	Meskine	90,00± 6,45	84,33± 8,96	81,33± 7,57	80,00± 1,73	81,33± 8,71	78,66± 5,78	80,33± 6,74	61,30± 3,68	64,66± 9,59	0,813
	Serre	75 ± 5,02	76 ± 4,59	69 ± 3,62	71,00 ± 7,21	74 ± 3,02	71 ± 2,58	73 ± 5,69	75 ± 3,25	70 ± 7,25	0,650
Lf42JAS	Mokolo	0,73± 0,25	0,70± 0,17	0,66± 0,28	0,76± 0,15	0,46± 0,05	0,56± 0,11	0,66± 0,15	0,70± 0,26	0,76± 0,11	0,611
	Meskine	0,70± 0,20	0,86± 0,15	0,80± 0,26	0,66± 0,20	0,63± 0,15	0,80± 0,17	0,60± 0,10	0,60± 0,16	0,66± 0,12	0,676
	Serre	1,04 ± 0,00	0,60 ± 0,06	0,60 ± 0,02	0,50 ± 0,01	1,00 ± 0,00	0,56 ± 0,01	0,80 ± 0,08	1,00 ± 0,07	1,30 ± 0,04	1,040

NB: DC: Diameter at crown in mm, HP: Height of the plant in cm, NF: Number of leaves, NR: Number of branches, LF: Length of leaves in cm, Lf: width of leaves in mm, JAS: Day after sowing.

3.4. Cultivation cycles of the different tigernut accessions according to the different culture conditions

Table 3 shows the number of days according to the different phenological stages of the different tigernut accessions.

Table 3: Crop cycle of the production of the different tigernut accessions according to the cultural environment.

Parameters	NJDT (greenhouse)	Number of days to physiological maturation			NJR (greenhouse)
Cultural environments	greenhouse	Mokolo	Meskine	greenhouse	greenhouse
Acc A	42,00 ± 0,50a	66,00 ± 0,57	52,00 ± 4,61	65,00 ± 2,78	71,00 ± 0,00
Acc B	45,00 ± 1,50ab	68,00 ± 1,15	54,00 ± 4,61	65,00 ± 3,00	71,00 ± 0,86
Acc C	45,00 ± 0,86ab	67,00 ± 0,57	52,00 ± 4,61	64,00 ± 2,29	70,00 ± 1,80
Acc D	43,00 ± 0,86ab	66,00 ± 0,57	52,00 ± 4,61	65,00 ± 2,00	71,00 ± 1,00
Acc E	46,00 ± 1,32b	67,00 ± 1,52	49,00± 0,00	67,00 ± 1,50	72,00 ± 1,00
Acc F	43,00 ± 4,76ab	56,00 ± 15,58	54,00 ± 4,61	63,00 ± 4,09	71,00 ± 1,80
Acc G	47,00 ± 2,00b	66,00 ± 1,15	54,00 ± 4,61	65,00 ± 2,91	71,00 ± 1,32
Acc H	43,00 ± 1,32ab	57,00 ± 16,74	57,00 ± 16,74	67,00 ± 0,00	72,00 ± 0,86
Acc I	39,00 ± 3,12a	67,00 ± 0,00	49,00 ± 0,00	64,00 ± 5,00	70,00 ± 2,00
P (sig)	0,020	0,453	0,511	0,093	0,051

NB: Acc: Tigernut accession, NJDT: Number of Days from start of tuberization, NJR: Number of Days at harvest.

It follows from this table that accessions A; D; F; H and I tuberized before 43 days after sowing (DAS). While accessions B; C; E and G tuberized from 45 days after sowing. In addition, on three different culture conditions, all tigernut accessions showed an earliness compared to the number of days of physiological maturation at the Meskine site, the maximum of which is 57 days after sowing with accession I. While this same accession I has 67 days after sowing like other accessions C, E and B at the Mokolo site. This shows that the spatial and geographical distribution has an influence on the cultivation cycle of the tigernuts tested. The short and medium cycles allow for better selection of varieties, but this choice depends on the yields obtained by the different tigernut accessions.

3.5. Performance components of different nutsedge accessions

3.5.1. Comparison of average yields between the different production conditions

Table 4 shows the average yield in t/ha and the weight in g of 100 seeds of different tigernut accessions according to the experimental environments.

Table 4: Yield in t/ha and weight of 100 seeds in g of the different tigernut accessions

Parameters	Yield in t/ha			Weight of 100 Seeds in g		
Accessions	Mokolo	Meskine	Greenhouse	Mokolo	Meskine	Greenhouse
Acc G	0,675 ± 0,147	0,218 ± 0,068	2,47±0,56^{c}	7,61 ± 0,67a	4,57 ± 0, 25a	10,1±0,40^{a}
Acc B	0,843 ± 0,109	0,410 ± 0,098	0,90±0,16^{ab}	22,9 ± 1,95e	13,74 ± 0, 36e	7,3±0,65^{a}
Acc I	0,898 ± 0,430	0,516 ± 0,056	5,37±0,56^{e}	47,6 ± 2,62f	28,56 ± 0, 86f	8,6±0,22^{a}
Acc H	0,906 ± 0,285	0,381 ± 0,181	1,44±0,08^{b}	35,06 ± 0,185f	38,10 ± 0,172g	7,6±0,52^{a}
Acc A	0,943 ± 0,067	0,401 ± 0,130	6,17±0,81^{f}	50,15 ± 2,05g	40,09 ± 0, 51g	16,6±0,41^{b}
Acc F	0,991 ± 0,400	0,478 ± 0,251	0,70±0,04^{a}	10,30 ± 0,89b	6,18 ± 0, 81b	5,2±0,29^{a}
Acc C	0,993 ± 0,180	0,505 ± 0,156	3,17±0,71^{d}	24,61 ± 1,83e	14,77 ± 0, 60e	9,4±0,28^{a}
Acc D	1,020 ± 0,175	0,330 ± 0,139	1,34±0,27^{b}	15,31 ± 0,79c	9,19 ± 0, 37c	7,5±0,24^{a}
Acc E	1,373 ± 0,633	0,340 ± 0,255	1,44±0,08^{b}	17,71 ± 0,68d	10,63 ± 0, 15d	6,3±0,31^{a}
P (sig)	0,462	0,358	0,000	0,000	0,000	0,015

It can be seen in table 4 that in greenhouse, six homogeneous groups were observed between the different tigernut accessions tested from the point of view of average yield in t/ha. These yields vary from 0.70t/ha to 6.17t/ha respectively with Acc F and Acc A, whereas in the field environment (Meskine and Mokolo), no significant differences in tuber yield were observed in the accessions tested. However, the yield values at the Mokolo site are high compared to the Meskine site. Between these two trial sites, the highest yield value at the Meskine site is 0.505 t/ha with Acc C while at the Mokolo site, the highest value is 1.373 t/ha with Acc E. In addition, the analysis of variance showed that there were highly significant differences in the weight of 100 seeds of the different tigernut accessions tested on three different conditions culture. In the greenhouse, the weight of 100 seeds of tubers per accession after harvest shows that Acc F had a low average of 5.2 g while Acc A had a high average of 16.6 g. However, on the Meskine and Mokolo sites, these same average values in weight 100 seeds vary between 4.57 g (Acc G) and 50.15 g (Acc A) respectively. It turns out that the weight of 100 tubers produced in a real environment (Mokolo and Meskine) is greater than that produced in a greenhouse. The search for high-performance yields in tigernut tuber does not allow a profit to be obtained from tigernut production. The evaluation in terms of cost and production gain of each tigernut accession allows for better decision-making in relation to the choice of promising accessions.

3.6. Economic performance of the different tigernut accessions by different condition of the culture

3.6.1. Income in CFA francs from tigernut accessions according to the different cultural environment

Table 5 shows that income from tigernut accessions varies from one condition culture to another.

Table 5: distribution of income in CFA francs from the different accessions of tigernuts by different cultural conditions

Nutsedge accessions	Mokolo (M)	Meskine (Me)	Serre (SE)
Acc G	742 500	239 800	2 717 000
Acc B	843 000	410 000	900 000
Acc I	718 400	412 800	4 296 000
Acc H	996 600	419 100	1 584 000
Acc A	1 194 469,81	507 934,67	7 815 353,9
Acc F	1 123 130,03	541 731,74	793 331
Acc C	1 092 300	555 500	3 487 000
Acc D	1 155 996,6	373 998,9	1 518 662,2
Acc E	1 441 650	357 000	1 512 000

At the Meskine site, Acc G recorded the lowest value in average income of around 239,800 CFA francs while the highest value was recorded at the Greenhouse level with Acc A with a value of 7,815,353.9 CFA francs. Generally speaking, most of the yields obtained on the Meskine site are not large enough compared to other site condition (Mokolo and Serre). The highest value on this site (Meskine) is 555,500 CFA francs with the Acc C. Identifying the best incomes is one step in choosing an accession, but determining the relative benefits of each accession will make it possible to better select the various promising accessions.

3.6.2. Profit in CFA francs from tigernut accessions by different condition of the culture

Table 6 shows the different benefits per tigernut accession depending on the different cultural conditions.

Table 6: distribution of profits in CFA francs from different accessions according on the cultural environment

Nutsedge accessions	Mokolo (M)	Meskine (Me)	Serre (SE)
Acc G	619 086,4	107 386	2 584 586

Acc B	740 290,4	298 290	788 290
Acc I	604 012,8	289 413	4 172 613
Acc H	873 186,4	286 686	1 451 586
Acc A	1 071 056	375 521	7 682 940
Acc F	1 008 825	418 427	670 026
Acc C	968 886,4	423 086	3 354 586
Acc D	1 041 692	250 694	1 395 357
Acc E	1 318 236	224 586	1 379 586

It can be seen from table 6 that the Mokolo site showed high profits with most tigernut accessions compared to the Meskine site. Whereas in greenhouse, the maximum profit (7,682,940 FCFA) is obtained with Acc A compared to the two environments culture (Mokolo and Meskine) whose maximum values (1,318,236 FCFA and 423,086 FCFA) are obtained respectively with Acc E and Acc C. From the above, accessions A; C; I; D; E and I seem promising for production, but the search for optimal profits would allow efficient production that takes into account the rational management of production inputs. The prioritization of production inputs requires an assessment of marginal resource productivity.

3.7. Marginal productivity in CFA francs of the production of the different tigernut accessions

3.7.1. Best combinations of tigernut production inputs

Table 7 shows the quantities and marginal productivity of production inputs for tigernut crops.

Table 7 shows that the optimal profit is 1,187,880.13 CFA francs for a better combination of production inputs relative to capital for the purchase of seeds; capital for the purchase of fertilizers, costs related to cultivation labor, depreciation of materials and equipment and the cost of renting plots of land at 42,874,020 CFA francs; 21,000 CFA francs; 2,127,360 CFA francs; 10,000 CFA francs and 3,225,806 CFA francs respectively. Only the costs related to the purchase of fertilizers and the depreciation of materials and equipment resulted in marginal productivity of 23,976 CFA francs and 68,438 CFA francs respectively. This best combination applies to an excellent treatment.

Table 7: Best combinations of output inputs from different accessions

Resources	Necessary Quantities	Availability Quantities	Marginal productivities

Cost of seeds	42 874.020	75 000.000	
Element fertilizer	21 000.000	21 000.000	23.976
Cultural labor	2 127.360	5 000	
Depreciation of materials and equipment	10 000	10 000.000	68.438
Rental of plots	3 225.806	20 000.000	
Optimal solution		1 187 880.13	

3.7.2. Best treatments for tigernut production

Table 8 shows the production activities par excellence of the different tigernut accessions according to the cultural environment.

Table 8 : Tigernut production activities par excellence

Nutsedge accessions	Serre (SE)	Mokolo (M)	Meskine (Me)
Acc G	-5.098E+6	-6.991E+5	-1.211E+6
Acc B	-6.895E+6	-5.779E+5	-1.020E+6
Acc I	-3.510E+6	-7.142E+5	-1.029E+6
Acc H	-6.231E+6	-4.450E+5	-1.032E+6
Acc A	0	-2.472E+5	-9.427E+5
Acc F	-7.013E+6	-3.094E+5	-8.998E+5
Acc C	-4.328E+6	-3.493E+5	-8.951E+5
Acc D	-6.288E+6	-2.765E+5	-1.068E+6
Acc E	-6.303E+6	0	-1.094E+6

The outcome of table 8 shows that one of the optimal solutions is deduced when the reduced costs (marginal product productivity) are zero. Therefore, with this better combination of inputs applied to these tigernut accessions, the production of A and E accessions are recommended activities respectively for the two environment conditions (in the greenhouse and on the Mokolo site).

4. DISCUSSION

4.1. Characterization of the different tigernut accessions

The visual description showed 7 groups within the different tigernut accessions tested on three different culture conditions. The group of accessions constituted would have a similarity from the point of view of certain quantitative and qualitative morphological parameters considered. This difference could be explained by a heterogeneity of varieties related to both the size and color of the tubers of the tigernut accessions. The origin of the seeds would also explain this diversity within tigernut accessions. Agromorphological diversity has been observed within the different accessions of African tigernut (Akabassi et al., 2022). The morphological characteristics (tuber, root, leaf, stem and inflorescence) presented 03 classes (ranging in color from light green, pale yellow and dark brown) among the local accessions of *Cyperus esculentus* collected from different localities in Benin (Adjahossou et al., 2021). There is considerable diversity in terms of climatic, genetic, habitat and morphological variability among nutsedge varieties (Okoli et al., 1997). Taxonomists have proposed several intra-specific divisions of the species based mainly on variations in floral structure (Abad et al. 1998). Based on the morphological characteristics of the seed, *Cyperus esculentus* would comprise two distinct varieties in Niger according to the size of the tubers, including the large and the small with several cultivars designated according to the producer (Toukoua et al., 2002). In Nigeria, three varieties (black, brown and yellow) are the most widely grown (Umerie et al., 1997). Of these, only two varieties, yellow and brown, are readily available on the market. The yellow variety is preferred because of its inherent properties such as its larger size, attractive color, and fleshier body (Belewu & Abodurin 2006). In general, the yellow nutsedge is the most recognized and preferred in all tigernut ranges. Similar studies by Sakatai et al. (2020) in Cameroon showed that maroon-colored accession with large seeds ("c = glazay") was the preferred choice of consumers in Cameroon due to its sweet taste and high market value. In terms of morphological diversity, growers identified 03 local accessions based on botanical traits, mainly tuber skin color and the presence or absence of inflorescence during the vegetative phase (Adjahossou et al., 2021). Results obtained by Saidou et al. (2020) showed that producers in Burkina Faso use color to distinguish tigernuts (a total of 108 accessions for ten different local appellations according to two brown and black colors) cultivated. Similar studies by Kabré et al. (2019) also showed that only the distinction of morphotypes of Hibiscus cannabinus L was also made on the basis of colors. Apart from this distinctive qualitative character, the maximum collar diameters of accessions A and I are of the order of 7.94 mm and 6.19 mm, while the smallest value in diameter was recorded with accession D (2.99 mm). For the maximum size, it varies from 68.33 cm to 85.22 cm for a variation of 8 to 12 leaves respectively with the B, D and A accessions. Quantitative characterization of tigernuts by Adjahossou et al. (2021) showed that the leaf width varies from 5 to 10mm and contains 6 to 30 flowers. The maximum size of tigernut accessions is 90 cm, with a length of 2 to 20 cm and a width of 4 mm (Akabassi et al., 2022). Tigernut tubers range in size from 0.3 to 1.9 cm in diameter. *Cyperus esculentus* is a perennial herbaceous plant that high vary the 30 to 70 cm (Adjahossou et al., 2021). This organ exists in two types: deep oblique rhizomes whose apical meristem differentiate a tuber and horizontal superficial rhizomes which give a new basal bulb bearing chlorophyllin leaves. In the Republic of Benin, 05 tigernut varieties have been identified based on certain criteria relating to the area sown, ethnic diversity and cultural importance of the species (Laly et al., 2019). In Burkina Faso, growers classify tigernut accessions on the basis of tuber colors, they found three morphotypes of *Cyperus esculentus*, two producing yellow tubers while the other producing black tubers while in Niger, the classification is based on the size of tigernut tubers (Bado et al., 2015; Bori et al., 2018). In Niger, there are two morphotypes of tigernuts, including the nutsedge and the large nutsedge (Bori et al., 2018). While on the basis of tuber color, three types of local accession (light yellow, brown and black) of *Cyperus esculentus* were recorded in the same Niger context (Adjahossou et al., 2021). Other authors had collected two phenotypes of *Cyperus esculentus* such as yellow and black when analyzing species diversity potentials in Benin (Sidohounde et al., 2019), characterization of tigernut accessions based on its oil extracted in Nigeria showed that accessions are categorized into yellow and brown color (Warra et al., 2017). The categorization of these 09 nutsedge accessions presented 04 distinct classes based on the traits taken into account. This morphological diversity that exists between these accessions is attributed on the one hand to the different phenotypic characters observed and on the other hand to the genomic traits related to these accessions tested. In terms of accession diversity, growers have distinguished only three types of landraces based on botanical characteristics, mainly tuber skin color and the presence or absence of inflorescence (Adjahossou et al., 2021). In the sub-Saharan zone of Africa, according to most of the producers surveyed, the three types of local accessions of tigernut grown come from three West African countries (Togo, Burkina Faso and Niger). In addition, on other crops, Hamissou et al., (2020) showed that the characterization of 140 sesames (*Sesamum indicum*) accessions from Niger presented 03 distinct groups based on 16 agromorphological traits. Studies of 22 onion genotypes based on 09 traits (plant size, bulb size, number of leaves, bulb date, yields, etc.) presented 05 distinct groups in terms of the ecotypes tested (Nikhil & Jadhav, 2016). Agromorphological characterization is the step in differentiating tigernut accessions, but cultural parameters are also criteria for separating cultivars from different species.

4.2. Crop cycle of the tigernut accessions tested

The 09 tigernut accessions tested in greenhouses showed a significant difference in the number of days of tuberization dates, the highest value of which is 47.00 days after sowing (DAS) with accession G while the smallest value is 39 DAS with accession I. In addition, the number of days of physiological maturation and harvest did not significantly differ between the different tigernut accessions regardless of the different conditions culture compared. However, the Meskine site showed an earliness of less than 10 days in terms of the number of days of physiological maturation of the tubers, regardless of the access of tigernut. A delay in the physiological maturation of tigernut tubers at the Mokolo site would be due to the influence of the altitude of the environment. It is likely that the maintenance of photosynthesis under stress conditions determines the survival of plants at high altitudes. Depending on the environmental conditions, the results show that the varieties differ from each other in relation to the cultivation cycle. In addition, reasons related to the crop cycle and morphological characteristics would also justify this heterogeneity within tigernut accessions. The choice of an accession also depends on the production cycles of the different tigernut accessions. It is therefore one of the short-cycle crops that has become the third export crop in terms of value for foreign exchange inflow after onions and cowpeas (Bori et al., 2018). It is only the landrace variety of tigernut, which has a relatively short cycle due to the early appearance of the inflorescences, which is distinctive of its physiological trait (Adjahossou et al., 2021). For this reason, in China, studies by Hu (2005) cited by Adjahossou et al. (2021) have shown that the emergence of inflorescences reduces the development of the species and prevents the development of tubers.

4.3. Yields in t/ha of the different tigernut accessions

Yield evaluation has shown that in a controlled environment (greenhouse), the highest yield can reach 6.17t/ha with Accession A whereas in the real environment (Meskine and Mokolo), a small variability in the yield of the tubers of the accessions tested was recorded. The highest value is 1.373 t/ha with Accession E. This high yield value at the Mokolo site shows that altitude has an effect on the yield increase of tigernut tubers. On the other hand, on the plains, termite constraints slow down the development of young plants, which sometimes inhibit the tuberization process. This leads to a drop in yield in the plains where humidity is quite high due to termite activities. The high yield observed in this condition culture (greenhouse) is justified by the fact that there was practically no loss of tigernut tuber compared to these two environment culture (Mokolo and Meskine) whose tuberization can reach a fairly deep depth.

These low tuber yields of the different tigernut accessions in real environments are due to the fact that there are tubers that could not be harvested at the field level due to the lack of control of the harvest profiles due to the deep root system of some tigernut accessions. The results of Sakatai et al., (2020) showed that the accessions "c= glazay" and "d= wéchéché" recorded the low average yields in t/ha (0.42 t/ha and 0.46 t/ha respectively) in the Mayo-danay area. This low yield of tigernut tuber is due to the fact that this locality is the preferred area for rice cultivation. In contrast, Beninese growers reported that tigernut accessions with light yellow tuber color had generally low yields, this is probably due to its inflorescence (Adjahossou et al., 2021). Consequently, the early appearance of the inflorescence would be at the origin of the low yield observed in Beninese producers. In addition, other reasons given show that this tigernut crop, which is characterized by limited agricultural investment because it uses rudimentary means to exploit the soil, a lack of investment in its production leading to a lack of soil fertilization policy leads to low factor productivity which leads to extensive cultivation of its production. Similar results from Larwanou et al. (2010); Sissoko et al (2011) showed that a significant part of production is lost due to the fact that the implements used are not well suited for harvesting. In addition, from a pedological point of view, this cultivation of wild Cyperus (*Cyperus rotundus*) causes the degradation of the soil structure on the one hand and can lead to the death of woody plants present on the fields on the other hand. But work by Kambire (2011) has shown that tigernuts perform better on soil rich in organic matter compared to other soil types. While the area occupied by tigernuts in the Far North is preferable sandy soils in order to facilitate harvesting. The same findings were made in Niger by Wourama et al. (2013) who showed that *Cyperus esculentus* cultivation must have a flat topography with sandy soils. The high yield values of the tigernuts tested show that accessions A (glazay) and E (Wéchéché) are recorded as they have recorded satisfactory results in tuber yield. In addition, the choice of tigernut varieties focuses on sweet tastes, and especially on the size and color of the skin. The degree to which the nutsedge accessions were assessed by the producers of the Danay-Vokgora locality showed that the 'c= glazay' accession was the subject of preference being given to the beneficiaries of that locality. This choice is based on the color and size of the tubers, producers explained in the focus groups that black accessions do not attract traders because of the price stability that would risk the loss of financial capital. Due to its less sweet taste (low sugar content) and especially its black color, which is not appreciated compared to other local tigernut accessions, black tigernut accessions are not cheap (Oladele & Aina, 2007). As Follak et al. (2016) shows, in the Nigerian market, the yellow and brown varieties of *Cyperus esculentus* are the most available in contrast to the black variety. Maduka & Ire (2019) also reported that this yellow-colored variety is the most attractive and occupies the largest area than other different color varieties.

4.4. Cost-benefit analysis of the production of the different tigernut accessions

The cost-benefit analysis of accessions A, F, C, D and E recorded substantial profits of at least one million CFA francs (1,000,000 CFA francs). This justifies that production with one of these accessions makes it possible to improve a producer's income to a satisfactory level. The high values for these tigernut accessions are mainly made up of brown tubers. It doesn't matter how big these tigernut tubers are, which shows that brown tubers are cheap. Studies by Saidou et al. (2020) have also shown that nutsedge of the same color tubers also provide a substantial income to women who produce this speculation. This type of local tigernut accessions are appreciated in the market with a financial profitability that can exceed other accessions of different colors (Adjahossou et al., 2021). This shows that the tubers of these accessions have potential, which could lead to the economic and social development of producers and the Burkinabe population in general. Depending on the production objective, some producers mainly produce tigernut tubers for sale (Warouma et al., 2013). This includes its export (tigernut production) to other countries such as Nigeria, which is a major center of consumption (Almou, 2008). This improves the average income per hectare of a producer in Niger by USD 823.40 (452,461 CFA francs from West Africa) (Bori et al., 2018). Thus, in recent years, people have taken an interest in the yellow nutsedge because of its high economic value of production. Similar results were found by Almou (2008) that yellow nutsedge is more popular with consumers in Mali. Maduka & Ire (2019) also reported that the large, brown tubers of Cyperus have an attraction compared to the black tubers. This is because black accessions are less attractive to traders because of its stable price, which risks the financial loss of capital and a very low sweet taste (Adjahossou et al., 2021). Overall, all tigernut accessions tested generated a profit that improved the income of small-scale producers in the Far North region. For example, Bamishaiye et al. (2011) reported that *Cyperus esculentus* contributes significantly to improving the incomes of smallholder producers and also to the socio-cultural values of people in rural communities in sub-Saharan Africa. The results of Bori et al. (2018) showed that tigernut tubers that were sold generate a significant income for producers in Niger.

4.5. Marginal Productivity of inputs from tigernut production

The determination of the best combination of the factors of production of the different tigernut accessions showed that it would be more profitable to produce with accessions A

(Glazay) and E (Wéchéché) respectively because the marginal productivity of the products (reduced cost) is zero. Similar results were obtained by Sakatai et al. (2020) in the Mayo-Danay area, which would be advantageous to produce with the "d= wéchéché" accession, because with the best combination of production inputs, its marginal productivity (73.09 CFA F) would be more profitable for the additional unit relative to the rental cost of the plot. Consequently, it has also been shown that the costs related to the purchase of fertilizers and the depreciation of materials and equipment generated marginal factor productivity of the order of 23,976 CFA francs and 68,438 CFA francs respectively. Variability in marginal factor productivity is explained by the fact that resource prices are largely dependent on the environment and period. This allows producers to better manage output inputs in factor market situations in order to provide better factor productivity. In general, the combination of factors imposes on farmers the need to improve their social living conditions through conversion to more profitable short-cycle crops (Ngapgue, 2007). According to Sissoko et al. (2011) in Mali, a woman can use 2 hours to harvest an area of 40 m². On other crops, for example, it has also been shown by Adjahossou et al. (2013) that the improvement of the financial profitability of the cropping system (groundnuts and maize) depends on the labor time factor, which is a major indicator of performance.

5. Conclusion

At the end of this study, the objective of which is the agro-morphological and economic characterization of 9 accessions of tigernut (Cyperus esculentus) in the Sudano-Sahelian zone of Cameroon. Indeed, the 09 accessions showed a difference from a qualitative point of view. Thus, 04 heterogeneous groups were recorded within 09 tigernut accessions taking into account agro-morphological parameters. The highest yields (6.17 t/ha and 1.373 t/ha) were recorded with Acc A and Acc E respectively in greenhouses and in the field. In addition, the highest values in profit were obtained again with Acc A and Acc E for values of 7,682,940 CFA francs and 1,318,236 CFA francs respectively. To obtain an optimal production with the best combination of inputs applied to these tigernut accessions, the production of accessions A (Glazay) and E (Wéchéché) are recommended activities respectively in the greenhouse and in the field (Mokolo). To complete this study, the type evaluation of fertilizations is one of the major steps for the improvement of the technical practice of tigernut production.

Annex:

Table 1: Evaluation of the production costs of the different tigernut accessions according to the culture media

Nutsedge accessions	Labor hj	Labor CFA F	Cost of seeds (CFA F)	Fertilizers (CFA F)	Depreciations CFA F	Rental of plots in CFA F in Mokolo	Selling price in kg and CFA F	Rental of plots in CFA F in Meskine
Acc G	671,88	3956,89	71456,7	35000	7000	6000	1100	15000
Acc B	731,77	4309,6	50400	35000	7000	6000	1000	15000
Acc I	539,06	3174,68	63212,5	35000	7000	6000	800	15000
Acc H	671,88	3956,89	71456,7	35000	7000	6000	1100	15000
Acc A	671,88	3956,89	71456,7	35000	7000	6000	1266,7	15000
Acc F	520,83	3067,31	63237,5	35000	7000	6000	1133,3	15000
Acc C	671,88	3956,89	71456,7	35000	7000	6000	1100	15000
Acc D	520,83	3067,31	63237,5	35000	7000	6000	1133,3	15000
Acc E	671,88	3956,89	71456,7	35000	7000	6000	1050	15000
Totaux	850	5000	75000	21000	10000	10000	1800	20000

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