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► **To cite this version:**

Oumar Hissein Abba Mahmoud, Oumarou Zango, Naoura Gapili, Maman Laouali Adamou Ibrahim, Abdoulaye Rafiou, et al.. Agrobiodiversity and Sustainability of Oasis Agrosystems in Palm Groves of Sahara and Sahel in Chad. *Journal of Agricultural Science*, 2022, 14 (4), pp.99-113. <10.5539/jas.v14n4p99>. <hal-04957302>

HAL Id: hal-04957302

<https://hal.science/hal-04957302v1>

Submitted on 19 Feb 2025

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Agrobiodiversity and Sustainability of Oasis Agrosystems in Palm Groves of Sahara and Sahel in Chad

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Received: December 21, 2021

Accepted: February 2, 2022

Online Published: March 15, 2022

doi:10.5539/jas.v14n4p99

URL: <https://doi.org/10.5539/jas.v14n4p99>

This research is supported by Sud Expert Plantes Développement Durable (SEP2D) program from the Institute of Research for Development (IRD/France) under the date palm Project AAP2-146 "Date Palm Agro-biodiversity in the Sahel".

Abstract

The cultivation of date palm, a pillar of oasis agrosystem constitutes a real source of development in arid and semi-arid zones because of its fruit's rich in sugars and various products, essential to daily life of the populations. In Chad, date production has experienced a decline since the sixties, in relation to diseases, pests and poorly performing cultivation techniques, environmental factors are major causes of the degradation of phoeniculture as well as insecurity and the phenomenon of rural exodus. In order to assess the potential of oasis agroecosystems based on the date palm in Chad, an ethnobotanical survey was carried out among date farmers of Sahara and Sahel. The cultivars of date palm is mainly cultivated in Sahara in the North of the country where it allows a rich and diversified subsistence agriculture (market gardening, fruit trees, cereals and fodder), which excludes the use of chemical inputs in production. Our study made it possible to highlight an important genetic diversity with more than 200 cultivars, resulting from empirical selection and multiplied by offshoot. In Sahara, date palms cultivars have only one fruit production season per year with satisfactory productivity, an acceptable price and farmers have a good knowledge of cultivation practises. In central part of the country corresponding to the Sahelian zone, oasis agrosystems are also found in basins. The climatic conditions favour two production seasons and the income from the sale of dates from the first fruit production season (April and May) is greater than those from the second production season (June to September). The strengthening of the local knowledge and the extension of palm groves made it possible to increase production and income and would contribute to food security and the maintenance of populations in Chad and more generally in Sahel's countries.

Keywords: agrobiodiversity, sustainability, date palm, Sahara, Sahel, Chad

1. Introduction

Chad is an agro-sylvo-pastoral country with an economy dominated by the agricultural sector. The various ecosystems found it containing a high plant genetic diversity (PND, 2017). The oasis agrosystem is generally characterised by mixed agriculture based on crop irrigation. This type of agrosystem is essentially based on palm groves defined as "a highly anthropized irrigated area which supports classically intensive and mixed farming" (Battesti, 2012).

The date palm (*Phoenix dactylifera* L.) is a dioecious monocotyledonous tree plant with allogamous reproduction from arid and semi-arid regions (Munier, 1976). The culture of date palm in Chad is practised mainly in the provinces located in Sahara in the North of the country and also in the basins of Sahel (Kanem and Lac Province). Little is known about the history of the introduction of date palm in Chad. Lazarev (1989) indicated that cultivation has been practised in Sahara (Borkou) since the 9th and 10th century while in Sahel (Kanem) it dates from the 18th century (Chevalier, 1930).

In Chad, two forms of date palm cultivation are found in the provinces of Sahara to the North due to the dry climate favourable to the cultivation of the date palm, comprising a traditional culture similar to that of phoenicultural countries of Maghreb. The biological cycle of the plant is classically characterised by an annual season of flowering and fruit production. On the other hand, Sahel is a marginal zone for the cultivation of the date palm because of climatic conditions encountered. Dates are produced during two fruit production seasons per year. The first season is equivalent to that of the Saharan zone but in Sahel, the rains occurring during the ripening of the fruits lead to the production of dates and inferior quality (Jahiel & Candelier, 1991). The second production season takes place in dry season but concerns a limited number of date palms. The number of date palms in Chad is estimated at around 2 million mainly located in Sahara (Ben Salah, 2015). This production made from Chad is the first country in Sub-Saharan Africa to produce dates. However, production has declined markedly since the 1960s (from 1961: 25,000 tons to 21,458 tons in 2019) (FAOSTAT, 2021) and this could impact the yield of associated crops. This production places Chad today in 22nd place in the world whereas it was in 15th place a few years ago. This could be explained by the impacts of climate change, fires in palm groves in the Sahara, political military conflicts and unsuitable farming practices. These multiple problems associated with the lack of socio-educational infrastructure lead the majority of young people either to rural exodus or to emigration.

Regarding the lack of knowledge on oasis agrosystems in Chad and on the date palm in particular, this study was undertaken to improve knowledge on the oasis agrosystem based on the date palm in Chad. It could help to assess the richness of heritage of date palm varieties and associated crops, besides investigate the socioeconomic aspects and cultivation techniques practised by the populations. An analysis of the strengths and weaknesses of date palm cultivation was also carried out to identifying prospects for date palm development in Chad. This would contribute not only to the improvement of the living conditions of the populations, but also the sustainable management of the oasis agrosystem in the face of global changes.

2. Method

2.1 Description of the Study Area

The current study was carried out in Saharan and Sahelian zones of Chad. In Saharan zone, two provinces were involved in the study (Borkou and Ennedi-Ouest) and in the Sahelian zone, only one province (Kanem) was touched (Table 1).

A total of four departments of Sahara were prospected during the survey including two sites (Faya and Borkou-Yala) in the province of Borkou and two other sites (Gouro and Ounianga-Kebir) in the province of Ennedi-Ouest. In Sahelian zone, the palm groves sampled were those find in Noukou and Mao Department in the province of Kanem (Figure 1).

Table 1. The 20 villages evaluated in the palm groves of the Saharan and Sahelian zones

Zone	Province	Departments/Cities	Villages
Saharian	Ennedi-Ouest	Ounianga-Kebir	Bourkoua and Eteh
		Gouro	Houkoubodo and Wildjaho
	Borkou	Kirdimi	Gourma, Kirdimi and Yen
		Faya	Tchangsous; Koukourou and Amoul
Sahelian	Kanem	Noukou	Barkadroussou; Yilgui; Andrah
		Mao	Kinitchi; Ailoum; Kouloula; Koumogari; Djougou; Mobeye; Barrah

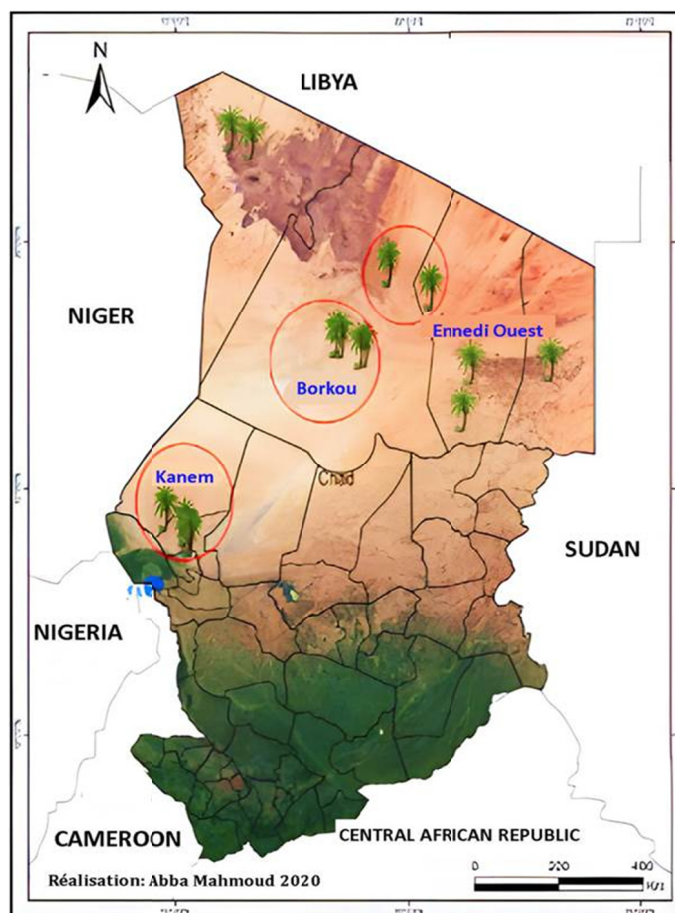


Figure 1. Geographical location of the study area, the palm trees represent the date palm-growing areas and surveyed palm groves are indicated by a circle

The climate of the Saharan zone is characterised by high heat and very low rainfall (less than 100 mm/year). In contrast to the Sahel that is characterised by rainfall ranging from 100 to 600 mm/year (ANAM, 2019).

2.2 Carrying Out the Ethnobotanical Survey

A total of 60 farmers were surveyed in the two study areas, with 30 farmers per area. These farmers are distributed in 20 villages. The approach was to do a group interview and an individual interview. The individual interviews were carried out in the farmer palm grove surveyed and the group interviews were conducted in the village under the gaze of traditional chiefs and rural development agents. An information collection form made it possible to identify local knowledge and cultivation practises, date cultivars, associated crops and the strengths and weaknesses of the sector. Data on the uses and local knowledge associated with them were collected, as well as on the production and sale price of dates.

2.3 Statistical Analysis

The quantitative and qualitative data obtained were pooled and the means standard deviations and frequencies were calculated using Excel software. The principal component analysis (PCA) was carried out using R software (R Core Team, 2020) to determine the relationships between cropping practices by zone (Sahara/Sahel).

3. Results

Activities related to date palm cultivation in the study area are dominated by men up to 95% and women represent only 5% of all farmers surveyed. Thus, only 20% of young people fewer than 40 years of age exercise activities in oases with an average age of 52 ± 10 years. It left between 32 and 64 years old respectively in Amoul and Eteh, in Saharan zone. Whereas in Sahel, this age is between 30 years in oases of Moboye and 65 years in Aïloum, Koumogari and Barah in the Sahelian zone. The producers of Sahara are almost from the Teda-Daza (Gourane) and Kanembou ethnic group in Sahel with the presence of Gourane also.

3.1 Diversity of Date Palm Cultivars and Nomenclature

In the areas studied, the identification of names of local varieties of date palm showed that the varietal diversity of the species varied from one locality to another. The names are generally attributed by the populations in local language of “Teda-Daza” in the Saharan zone and in “Kanembou or Daza” language in the Sahelian zone. Varietal recognition in Sahara is generally done in relation to the morphology of the plant, the phenotype and the organoleptic properties of the fruits. There are over 200 cultivars in this region (see Appendix A).

In Sahel, although a significant diversity of forms has been observed, farmers reveal that they can only differentiate cultivars through the characteristics of the fruits. The main criteria for classifying and naming cultivars in Kanem are consistency (soft or hard) and colour (Bara, kifi, lia, signify red, yellow, and white, respectively) which determine the three cultivar groups of Sahel.

In Sahara, the cultivar most widely used in almost all production areas is “Brounow” because of its good productivity, ease to storage the quality of its fruits for marketing (dry date) and its adaptation to the climate. In second position comes the cultivar “Anago”/“Anaga”, which is precocious with semi-soft dates very fleshy and delicious; it’s all these characteristics that determine the preference of varieties by the population. At the level of each province, specific cultivars of a locality are also present for example of “Yesma”, “Horeido”, “Mayesko” and “Hawarbellah” in Gouro basin, “Djanneh”, “Hadimideh” and “Merdeh” in Ounianga-Kébir basin. On the other hand, in Borkou Province (Faya and Kirdimi department) there are cultivars specific to the area such as “Zalanga” and “Zalao”.

In each locality, a good number of early cultivars more productive and more valued by the population have been identified. The cultivars “Bournow” and “Anago” still have a good place in the Saharan zone because of their good characters appreciated by the farmers, the seller and the consumers.

In Sahelian zone, the cultivars “Blatatschi”, “Wourdeh” and “Wallerom” are the most popular. Male date palms are not as well characterised as female palms because growers place little importance on the origin of pollen. As a result, in some plantations the number of male individuals is low (≤ 3 individuals/+ 100 female individuals) whose pollens are sought in neighbouring palm groves.

3.2 Richness and Diversity of Associated Cultures In Date Palm

The date palm in oases of Chad as in all oasis agrosystems offers ideal conditions for the association of crops. This production technique is an opportunity to meet the food needs of the local population. In Sahara, market gardening is generally practised under palm trees (underlying) and in association with palm trees in Sahel basins. This study made it possible to inventory a total of 42 crops in Sahara including 29 market garden species, 8 fruit species, 3 cereals, 1 fodder crop and 1 legume (Figure 2). In Sahel, we have identified 40 crops associated with date palms: 27 vegetable crops, 6 fruit species, 4 cereals, 1 fodder crop and 2 legumes (Figure 2). (List of species: see Appendix B). These different cultures considered as food crops cover the daily needs of the population. In some palm groves of Gouro (Sahara), the breeding of small ruminants is practised by farmers.

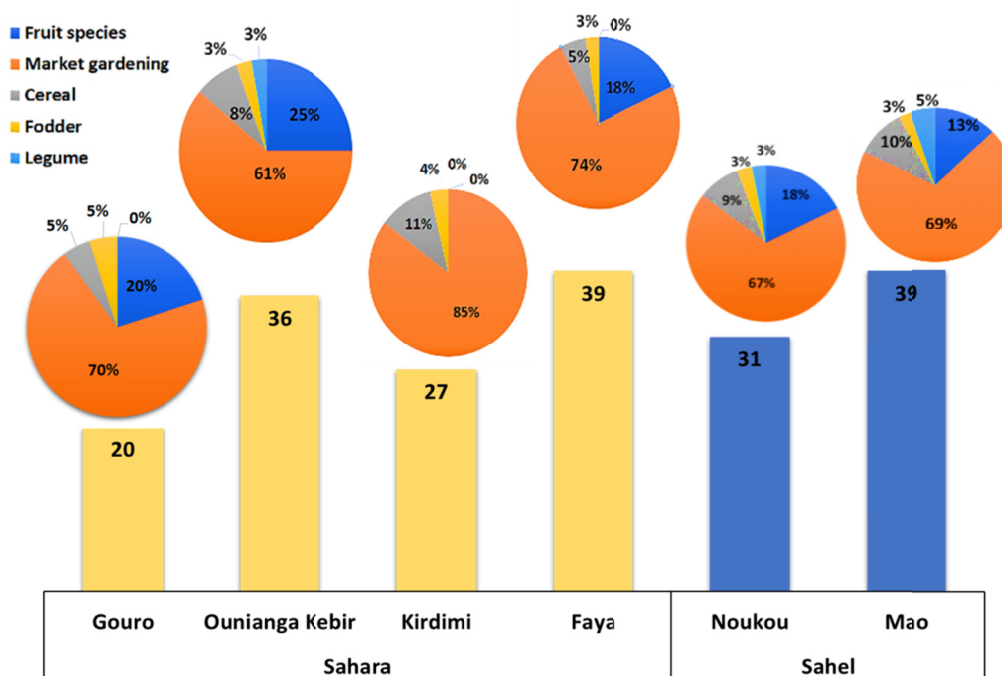


Figure 2. Crops associated with the date palm. The histograms correspond to the total number of crops and the pie charts correspond to the frequencies of crops in the palm groves of various departments studied in Sahara and Sahel zones

3.3 Multiple Food and Social Uses of Date Palm in Chad

In three provinces studied (Borkou, Ennedi-Ouest and Kanem), the use of date palm fruits by date farmers was primarily for local human consumption, commerce and a small amount for livestock feed. The proportion of dates sold per village is between 90% in Tchangsous in Borkou (Sahara) and 47% in Djougou in Kanem (Sahel). The average proportion of dates sold is $71 \pm 14\%$ distributed between 76% in Sahara and 60% in Sahel. Dates are eaten as a fruit or after processing into pasta, porridge and African ball or are used in the preparation of tea and syrup. They are rarely used to produce beer or liquor.

Dates are generally consumed or sold in fresh form in the production area and dry dates are transported to large cities for sale. The method of consuming or selling dates varies from Sahara to Sahel. In Sahara, dates are eaten at the stages: “Bser: yellow or red”, “Rotab: red” and “Tamr: dark red or black”. While in Sahel they are also consumed at the “Khalal: bright green” stage. The income obtained from this activity is used among other things for the needs of the family, the education of children, the upkeep of the field and the trade or small breeding.

From Sahara to Sahel, date palm is a plant of great importance not only because of its fruits which constitute an important food resource but also of the multiple uses of all the parts in particular the stipe, palms, fibers or nuclei. The main uses mentioned are in particular firewood, the manufacture of bed construction materials, chairs, wardrobes, mats, ropes, trays, curtains (blinds), leaf baskets and fan palm, etc. It is also used in the construction of roofs of houses, sheds and others. Despite this diversity of processing, this activity is still traditional and its use mainly covers the needs of farmers in rural areas.

3.4 Knowledge and Practices of Local Producers

The date palm cultivation systems in Sahara of Chad are based on ancestral knowledge and practices passed down from generation to generation. These practices are assessed with regard to their degree of implementation by farmers in two zones (Figure 3).

The principal component analysis made it possible to observe cultivation practises exclusively practised by Saharan farmers (fertilisation, irrigation and propagation by offshoot) of date palms. On the other hand, date palm multiplication by seed sowing is frequent only in the Sahel. Certain practices are implemented in two areas: manual pollination, pruning of fins during the rest and the burning technique. In Sahara, the propagation of palm trees is done exclusively by offshoots and in Sahel it is done largely by sowing even if sometimes offshoots are

planted. The distance between plants is 3 to 8 m with an average of 5.5 m in Sahara against 2 to 4 m with an average of 3 m in palm groves of Sahel. The proportion of female plants per field is $85\pm 10.25\%$ in Sahara, against $73\pm 3\%$ in Sahel.

Manual pollination of date palms is practised by all producers. It is done by inserting 3 to 6 male spikelets into the female inflorescence. No reduction of female inflorescence spikelets is performed by growers either before or after pollination. As for the pruning of dead palms, it is usually done during the date production period in both areas. In Saharan zone, date palms are irrigated by farmers during fruit production. The drainage irrigation system is mainly used in the province of Borkou (78%) while motor pumps to lift water from wells are more used in Ennedi-Ouest (83%). Some farmers draw water from wells manually to irrigate their date palms. Fertilisation of soils intended for the cultivation of the date palm is only practised in Sahara. Organic manure is more used in Ennedi-Ouest natural fertilizers commonly called “Tilli” by the natives of Borkou are collected in quarries to fertilize the soil. On the other hand, in Sahel (Kanem), 6% chemical fertiliser is used by farmers with the aim of enriching the soil for vegetable crops. The use of the slash-and-burn technique as well as the reasons for its use vary little from one zone to another (33% in Sahara and 23% in Sahel). It is used mainly to clean the fields according to the producers.

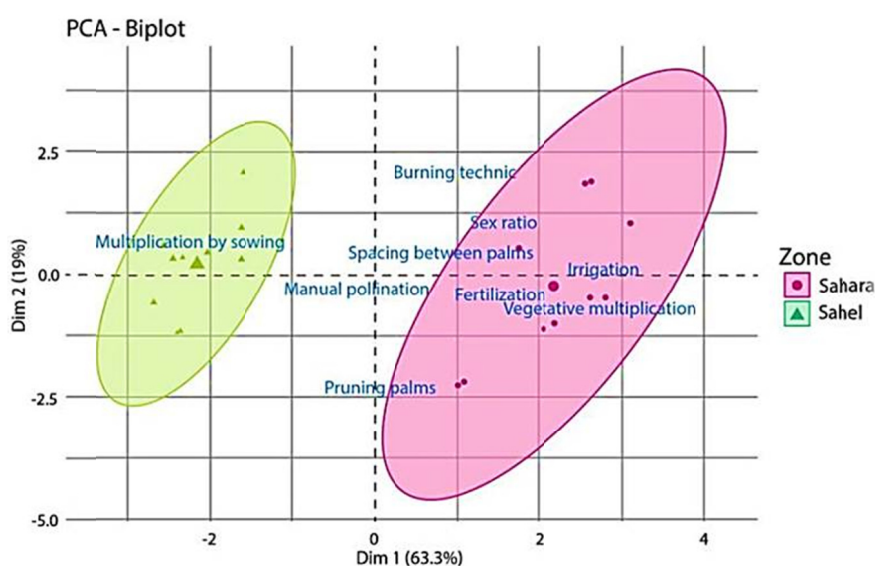


Figure 3. Implementation of cultural practices in Sahara and Sahel provinces, Each point represents a village surveyed

3.5 Productivity and Selling Price of Dates

The fruit production periods are different in Sahara and Sahel regions. In Sahara, date palms have a single date production campaign which generally begins at the end of May and ends in September and which is equivalent to that encountered in Maghreb countries. On the other hand, climatic conditions in Sahel favour two production seasons. The big date harvest campaign takes place from May to September and corresponds to that which takes place in Sahara. The first production period coincides with the dry season, with the date harvest taking place between April and May. In Sahel, 20% of individuals have a double flowering and therefore experience two production seasons. For the 2017-2018 campaign, the average productivity of a date palm in Sahara varied from 38 kg per plant (Gouro /Ennedi-Ouest) to 100 kg in Faya/Borkou basin with a general average of 68 ± 19 kg per plant due to 55 kg in Ennedi-Ouest and 76 kg in the province of Borkou (Figure 4). In Sahel, productivity is lower between 19 and 55 kg per plant respectively in the villages of Kinintchi and Djougou (Kanem) with an average of 39 kg for the first campaign and 18 kg for the second campaign (Figure 4).

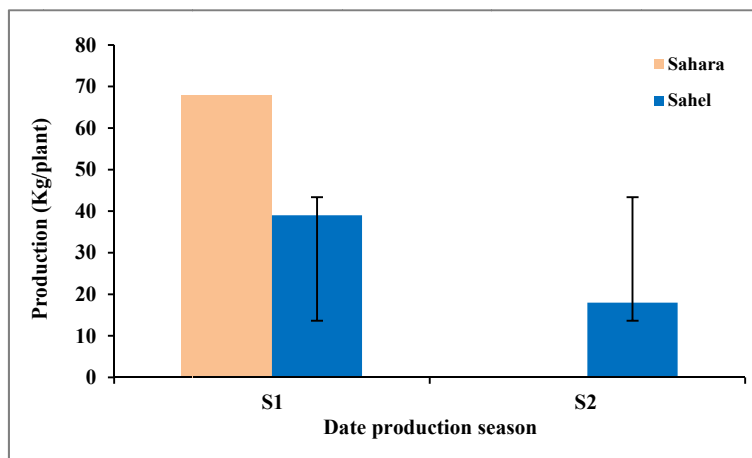


Figure 4. Date productivity in Sahara and Sahel provinces. S1: first fruit production season; S2: second production season

The price of a kilogram of dates in the Saharan zone varies little from village to village. It is between 407 F CFA in Gourma (Borkou-Yala) to 633 F CFA (Bourkoua/Ounianga-Kebir) with an average price of 506 F CFA/kg. In Sahel, the price per kilogram of dates during the first season varies between 198 to 493 F CFA respectively in Yilgui (Nord-Kanem) and Ailoum 1 (Kanem), and for the second production season the price varies from 350 to 907 F CFA, respectively in Yilgui and Djougou (Kanem). The average price of a kilogram of dates is 326 and 685 F CFA during the first and second season respectively (Figure 5).

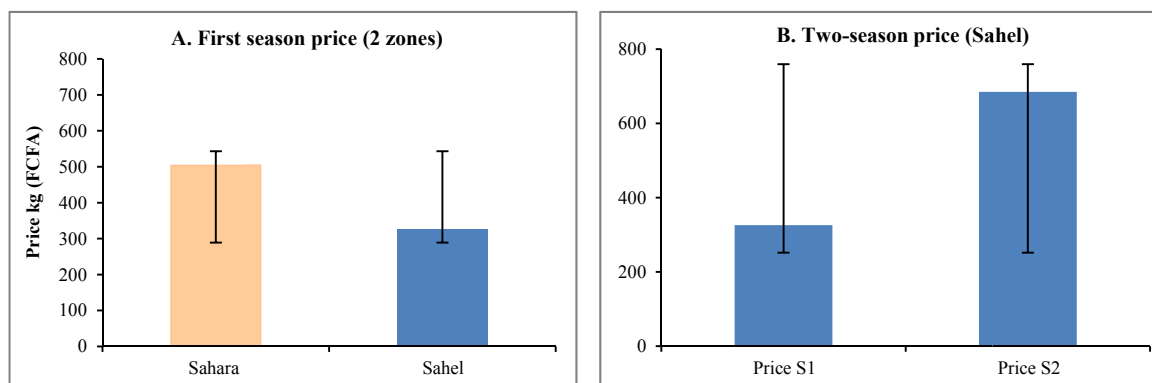


Figure 5. Price per kilogram of dates in Sahara and Sahel provinces; A: First season fruit production price in 2 zones; B: Price for two fruit production seasons in Sahel. S1 = first production season; S2 = second production season

3.6. Limits and Solutions of Phoeniculture in Sahara and Sahel Provinces

During the surveys carried out in two zones (Sahara and Sahel) we were able to demonstrate that phoeniculture is essential to the life of populations and that it's the main source of income in arid and semi-arid zones. However, several constraints limiting production have been reported by farmers.

In Saharan zone, rainfall is very low but an increase has been observed in recent years causing rains in several localities, especially in the department of Kirdimi, causing enormous damage to dates during drying or by flooding the stores of storage. Other impacts of climate change characterised by the retreat of the water table and the silting up of palm groves are also frequent in the two zones. Pests and diseases of the date palm have an impact on the yield in quantity and quality because of the absence of control intervention. The traditional skills of farmers of Sahara seem satisfactory, but challenges remain. The water supply to crops is a determining element that directly impacts yields. In Saharan zone, mainly in palm groves of Faya where irrigation is practised, farmers note a lack of water supply which is due to the state of degradation of irrigation systems dating back several decades and

suffering from lack of maintenance. The difficulties in storing soft dates are among other factors limiting the development of phoeniculture. The most important challenge for the management of the heritage of the date palm is to limit the fires of various origins which constitute a threat to phoeniculture. In addition, the creation of socio-educational infrastructures and the financing of initiatives by women and young people could stop the rural exodus and increase their involvement in date palm activities. Capacity building for technicians and farmers in terms of agricultural routes should be considered to ensure sustainable development of date palm cultivation in particular and the oasis agrosystem in general (Table 2).

Table 2. Limits and prospects for the evolution of phoeniculture in Sahara

Challenges	Problems	Solution/mitigation
Climate challenges	Silting	Mechanical and biological control
	Increased rainfall (post-harvest losses)	Bagging of date regimes
		Construction of storage warehouses
Anthropogenic challenges	Poorly performing cultivation practises	Training, knowledge transfer and introduction of new technologies (diet bagging, inflorescence reduction...)
	Ageing of the palms	Extension and creation of new plantations
	Degradation of irrigation systems	Reinforcement of irrigation system
	Low water control	Construction of drainage channel and rational management of water/taste system
	Rotting of soft and semi-soft dates	Development of conservation and processing techniques (value chain)
Challenges in the management of genetic resources	Decrease in varieties (fire in palm groves)	In situ conservation of date palm genetic resources Palm renewal
	Lack of a national catalogue of varieties	Characterisation of the main cultivars with a view to their registration and conservation
Challenges pests and bioaggressors	Diseases and pests (drop in production)	Integrated management
Infrastructure challenges	Lack of Access Road	Road construction
	Insufficient socio-educational structures	Strengthening of structures
Demographic Challenges	Rural Exodus	Reinforcement of basic socio-educational structures
	Aging of Farmers	Investment of youth and women
	Disaffection of young people and women	

For the Sahelian zone, where phoeniculture is more recent, the difficulties are significant. The survey made it possible to discern several weak points at the level of the basins such as the late identification of the sex of young date palms from seed sowing and consequently the high number of male parents in the fields, ignorance of cultural practices (irrigation, fertilisation, isolation of offshoot, etc.), attacks on fruits, especially dates by bats and a drastic reduction in the surface area of the pits, largely due to silting up. In addition, climate change in the Sahelian zone has led to a reduction in rains which has the consequence of reducing production in palm groves, especially since the date palms in this zone only benefit from rainwater for their irrigation (Table 3).

Table 3. Limits and solutions for the development of phoeniculture in Sahel

Challenges	Problems	Solution/mitigation
Climate challenges	Decrease in rainfall	Construction of boreholes
	Sand lasting of basin	Mechanical and biological control
Anthropogenic challenges	Poorly controlled cultivation practises	Training, knowledge transfer and introduction of new technologies
	Ageing of the palms	Creation of new plantations
	Late sexing of palms	Genetic sexing
	Lack of palm tree irrigation	Multiplication by offshoot
	Insufficient pollen during the 2nd flowering period	Boreholes and water drainage channel
	Date rot due to humidity	Setting up of a pollen conservatory
Challenges in the management of genetic resources		Bagging of date bunches valorisation of the 2nd flowering
	Few double flowered palms	Creation/selection of new varieties
	Few early maturing palms	Creation of new palm groves
	Ageing of date palms	Creation/selection of new varieties Creation of new palm groves
Challenges pests and bioaggressors	Bat invasions	Extension of palm groves
	Diseases	Implementation of control programs
Infrastructure challenges	Lack of Access Road	Implementation of control programs
	Insufficient socio-educational structures	Road construction
Demographic Challenges	Rural Exodus	Strengthening of structures
	Ageing of Farmers	Reinforcement of basic socio-educational structures
	Disaffection of young people and women	Investment of youth and women

4. Discussion

4.1 Diversity of Date Palm Varieties in Saharan and Sahelian Zones

The present study has shown that in the Saharan zone, there is a much greater varietal richness than in Sahel; respectively of 200 and 3 groups of cultivars based on the colours of the fruits (green, yellow and red). These results are close to those obtained by Barkaï (2010) who identified 149 cultivars in Sahara of Chad (Borkou and Ennedi-Ouest). Belguedj in (2007), mention that there are 940 cultivars in the Algerian palm grove and Almansoori et al. (2015) have documented more than 100 cultivars in Bahrain. The estimate of varietal diversity for the date palm in the world is in order of 5,000 cultivars according to Jaradat and Zaid (2004) and 3,000 cultivars according to Johnson (2011). The great diversity of date palm cultivars in Sahara of Chad is explained by the ancestral aspect of the cultivation of dates in this zone (more than 1,000 years) which has allowed an empirical selection of varieties over time and has made possible the constitution of a heritage of varieties adapted to local conditions and to the needs of the populations. The traditional knowledge of Sahara farmers has allowed the clonal propagation of the cultivars selected by the culture of offshoots thus favouring the conservation and the fixing of their characteristics transmitted thus from generation to generation.

In Sahelian zone of Chad, there are mainly three large groups of varieties which are multiplication by seeds, identified by the colour of the fruits as well as other lesser-known cultivar subgroups. This low varietal diversity could be due to the more recent introduction of the date palm in this area (200 to 300 years). In addition, the nomenclature of cultivars is preserved from one basin to another due to the low ethnic diversity of date farmers (Kanembou and Gourane). Cultural practices linked to the cultivation of this species are less mastered by the date farmers of Kanem (Sahel). Multiplication by seeds not clonal leads to a potential loss of the characteristics of the selected varieties. In this region, they are therefore more “population varieties” than true clonal varieties. These results are consistent with those obtained in Niger by Jahiel and Candelier (1991) who reported three cultivars propagated by seeds in the Manga region of Niger. In contrast, Zango et al. (2016) identified 16 cultivars in this region. The peculiarity in this area is that cultivars propagated by seeds can have several names linked to the ethnicity of the cultivators (Abdoussalam & Pasternak, 2015; Zango et al., 2016). The date production areas in Chad are similar to those in Niger, namely a traditional area in Sahara and another marginal area in the Sahel. In the

traditional zone of Chad, date palm propagation is nowadays only done by offshoot, but in Niger it is also done by sowing seeds (Ahmed et al., 2011; Abdoussalam & Pasternak, 2015). In Sahara, cultivar names are given by farmers in the Tédá-Daza/Gourane (Doza) language, these names can have two common names based on the accent and pronunciation, as mentioned by Tarrieux (1930).

4.2. Chemical-Free, Rich and Diverse Subsistence Agriculture Associated With Date Palm in Oases of Chad

From Sahara to Sahel, palm groves provide a favourable environment for the cultivation of many species associated with the date palm. These crops (market gardens, fruit and fodder) are generally irrigated except for seasonal crops (maize, pearl millet, sorghum, wheat and sugar cane) and legumes (groundnuts and cowpeas) which are cultivated in Sahel during the rainy season. Market gardening is the underlying crop most widely used in palm grove environment. The palm groves of Faya are favoured by the availability of an irrigation system and the good position of its palm groves in the city. Arboriculture in palm groves of Ounianga-Kebir is more represented than in other localities due to the proximity of Lake Ounianga. The latter provides a regular water supply to the shrubs. In monoculture without associated cultivation, the production of the date palm varies widely from 35 to 100 kg per plant. When grown in combination with another crop (market gardening and fruit trees), its production is much more stable with values between 50 and 65 kg per plant. This could be explained by the maintenance provided by the farmers and the irrigation of the fields due to the presence of underlying crops.

In Saharan zone of Chad, the underlying crop is practised by 91% of farmers, against 71% in Sahel. The operators of Ouargla palm grove in Algerian Sahara also cultivate the underlying crops at 94% (Faci et al., 2017). The practice of associated crops is the characteristic of the phoeniculture areas of the Maghreb and is part of the traditional management and enhancement of palm groves. This diversity of crops not only allows the production of a rich and diverse food resource but it is also a source of additional income for producers. Products from the underlying crops are usually consumed locally or sold in surrounding markets. Our results are confirmed by a recent study by Tilman et al. (2019), which suggested that two factors: irrigation (compensating the random rains) and agrobiodiversity (determinants in the stability of production systems).

4.3 Promotion of Products From the Date Palm in Sahara and Sahel

From Sahara to Sahel, the various products and by-products from the date palm are widely used. It is mainly the dry dates, the soft dates and the palms which are used in human or animal food either locally or sold through traders in almost the entire country. Marketing is done using the local currency (F CFA) unlike the colonial era when the date trade was done through exchanges with sugar, sheep or clothing (Baroin & Prêt, 1993). In Sahel region, dates are little processed compared to Sahara due to the high demand for fresh dates. Various artisanal by-products are made with palms (baskets, mats, fan, furniture curtains, awnings, etc.), stipes (framework activities) and fibrillum/lif (a kind of plant weaving, ropes) of date palms. These uses date palms have been practised for a long time in the Sahara, especially in Borkou (Baroin & Prêt, 1993), as in the phoenicultural zones of North Africa and the Middle East, but they are less developed in Sahelian region.

4.4 Wealth and Diversity of Management of Peasant Practises in Sahara and Sahel

The comparison of knowledge and mastery of cultivation techniques implemented by date palm farmers in Chad shows a clear difference between the regions of Sahara and Sahel. Elaborate agricultural practices are observed in Sahara, a traditional production area. Indeed, the propagation by offshoots, high spacing between the feet, assisted pollination, irrigation and fertilisation of soils are considered as essential factors to the quantitative and qualitative improvement of the production of dates (Zaid & Wet, 2002; Benziouche & Chehat, 2010). These observations are confirmed by the high productivity of date palms in this area which excludes all kinds of chemicals in the treatment of date palms and the lack of irrigation water control in some palm groves of Borkou. In Sahel, only assisted pollination is practised by farmers while propagation by offshoots, fertilisation, irrigation and sufficient spacing between the date palms are not practised. Similarly, pruning of the spikelets of the female inflorescence is not carried out by growers either before or after pollination although this practice contributes to improving yields. In Niger, this cultivation technique is used much more since 96.66% of farmers in Sahara and 57.14% of farmers in Sahel reduce the number of female inflorescences (Ibrahim et al., 2020).

The proportion of female plants per field in phoenicultural regions (Maghreb and Middle East) is on average three male plants per 100 female plants (Zaid et al., 1999). A high proportion of female plants per field allow the optimisation of the use of cultivated areas for fruit production. The low rate of male plants requires assisted pollination to ensure satisfactory pollination of female plants. A single male individual can manually pollinate 50 to 60 female individuals in plantations (Aberlenc et al., 2010).

This study also made it possible to determine the proportion of female plants which is 85% in Sahara and 73% in Sahel. These results correspond to the recommended ratio which is 80% female plants and 20% males (Maiga, 2010). Our results are slightly different from those obtained by Zango et al. (2016) in the region of Manga in Niger, which is 68% female and 32% male, and largely different from those obtained by Togo (1997) in the region of Kidal in Mali, which identified 47% female.

Date palms in the Sahara are fertilised with “*tilli*” (a natural fertiliser), whereas in the Sahel less care is given to this plant, because fertilisation is done just for the beds intended for market gardening. This situation is similar to that of the Ouargla region in Algeria (Faci et al., 2017). The spacing between the date palms in the two areas is below the standard laid down in the date palm cultivation protocol, which is about 6 × 6 m (an average of 5.5 m). On the other hand, our results are higher than those observed by Aregawi et al. (2018) at the level of the Afar region in Ethiopia. The technique of burning dry palms is not widely applied by the majority of farmers, only 33% in the Sahara and 23% in the Sahel. These results are equivalent to those observed in Niger by Ibrahim et al. (2020).

4.5 Satisfactory Productivity and Prices in Sahara and Strong Potential for the Second date Production Campaign in Sahel

Chad produced in 2019, 21,458 tonnes of dates (FAOSTAT, 2021) with an overall profitability of over 10 billion CFA Francs. The Saharan zone with 2 million feet of date palm providing good quality dates represents 97% of this income. However, the isolation of this area and its remoteness (more than 1,000 km from the Chadian capital) entail high costs for transporting production to the provinces, large cities and neighbouring countries that do not produce dates. On the other hand, Sahelian zone represents only 3% of total production and provides dates of inferior quality, generally consumed fresh in the production zone or transported to N'Djamena or to other towns in the country.

During the first production season, which takes place between May and September, the yield of a date palm is on average 68 kg per plant in Sahara and 39 kg in Sahel. These yields are lower than those reported by Baroin and Prêt (1993), who estimated the average yield at 100 kg per plant in maintained palm groves of Faya in Sahara of Chad in the 1990s. Its figures are below the expected standards of date palm productivity, which is 80 to 100 kg per plant (Benzouche & Chehat, 2010). The low productivity observed in Chad could be due to the effects of climate change, aging of date palms and enemies of this species.

The Sahelian zone is characterised by a second date production campaign (April and May) with a low yield (18 kg per plant) but the dates produced are of very good quality and have a high selling price. This campaign could turn the Sahelian zone into a true phoenicultural zone by selecting the cultivars which fruit during this period. Dried dates are generally sold by Coro (a bowl which weighs around 2.5 kg). The proportion of dates sold is 76% in Sahara against 60% in Sahel.

In this study, an assessment was made on the price at which dates are sold by farmers in the production area often in their fields. Soft dates are sold by heaps or bunches at an exorbitant price (almost 50 F per fruit) (Report, 2015) in the production areas, notably in Faya (Sahara). The sale price in the different towns varies according to the circuit of wholesalers and traders. For example, in N'Djamena, the price varies from one cultivar to another; it is between 1,250 and 1,700 F per kg. This price is high compared to the prices practised at the Boutti market in Niger, reported by Zango et al. (2016), *i.e.*, 1060 F per kg for dry dates. The income generated by phoenicultural activities covers the daily needs of the populations who are in most cases temporary farmers in the palm groves.

4.6 Outlook for Date Palm Cultivation in Chad

Our study makes it possible to define ways of improving and developing phoeniculture in Saharan and Sahelian zone of Chad. In Saharan zone considered suitable for the cultivation of the date palm, farmers show a desire to expand and create new palm groves and their need to strengthen their knowledge in terms of cultivation practises. In Sahelian zone, the desire to create palm groves is also present among farmers who wish to benefit from improved varieties of date palm as well as the introduction of new agricultural technologies. Women, considered as a pillar in the development of the rural world, must be strongly involved for a sustainable development of oasis activities. Consequently, the development of date palm cultivation certainly involves building the capacity of farmers in terms of technical itineraries and the structuring of farmers. In addition, the creation of a new date palm cultivation area must be highlighted to ensure the sustainable development of this culture. Chad comes fifth in Africa in terms of groundwater with a volume between 26,600 and 112,000 km³ (MacDonald et al., 2012) while this resource is currently very little exploited. The country also has a great potential of cultivable land in all zones (39 million ha) and 5.6 million ha of irrigable land, which 335,000 ha are easily irrigable (MAI, 2013). Unfortunately, only around 3 million ha is currently in use, which only a few dozen is used for the date palm cultivation. A particular intention must take into account the sustainable management of water and soil, the

mechanical and biological fight against the silting up of oases and basins, and the reconstruction of abandoned palm groves for a sustainable management of ecosystem services. The creation and strengthening of support services for farmers so that they can fully assume their functions in terms of farmer organisation, agricultural advice and credit granting. Similarly, strengthening socio-educational infrastructure and basic infrastructure are also important for the development of the Sahelo-Saharan zone.

5. Conclusions

Our study on the agrobiodiversity of the oasis agrosystem in Saharan and Sahelian zone of Chad shows that the date palm occupies an essential place in the socioeconomic life of the oasis agrosystem. However, there are some important differences between the two areas. We find characteristics of traditional palm groves in Sahara compared to the Sahel which is a marginal zone. There is a better control of the practices in Sahara compared to the Sahel which results in a better profitability of the plantations. The Sahara and Sahel zones in Chad present a strong potential for the cultivation of date palms and to be part of the sustainability, development and extension of palm groves will have to take into account the forecasts of the climate change in the zone. The information collected opens the way for the optimisation of cultivation practises for the sustainable use and conservation of the local agrobiodiversity of date palms, in particular the oasis agrosystem in order to contribute to the Sustainable Development Goals (SDGs), in particular, eradicate poverty and hunger, ensure food security and promote sustainable agriculture.

Acknowledgements

This research was financed by Sud Expert Plantes Développement Durable (SEP2D) program from the Institute of Research for Development (IRD/France) under the Project AAP2-146 “Date Palm Agro-biodiversity in Sahel”. Thanks to farmers and village leaders who have agreed to work with us and to share us their ancestral knowledge. We offer our appreciation to technicians from rural development agency (ANADER) for their assistance during the survey mission. Authors also thank Dr. Djondang Koye, Yassin Doudoua, Dr. Nadjiam Djirabayé, Emmanuel Ehnou Gongnet, Bienvenu Koguyam and Abdoulaye Abakar Tcheguelei for the help and supports.

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Appendix A

List of recorded cultivars of date palm in the two zones and ethnic groups

Province	Department	Ethnicity	Name your varieties (local names)	Earliest variety	Most productive variety	Most popular variety
Saharan Zone						
Ennedi-Ouest	Gouro	Toubou, Anakaza, Toleh	Kouhou, Brounow, Anago, Martchano, Mezini, Kodow, Ozounow, Houreido, Kouhidow, Kow, Mayaskor, Yesma, Ozina, Memodo, Korrido, Linguído, Horeido, Fohanido, Foraida, Dalamalou, Gnogo, Kohada, Donali, Hassa, Firidow, Hawarbellah, Horeido, Thordo, Hawarbellah	Anago, Kouhi	Horeido, Brounow, Mayesko, Anago	Anago, Brounow, Horeido, Martchano
	Ounianga-Kebir	Ouadjangué, Ougné	Djanneh, Kohani, Hadimideh, Kougoudow, Tahordeh, Wallao, Tafourde, Brounow, Adjam, Martchano, Okom, Anago, Kamani, Kohami, Merdeh, Konini, Djamah Djanneh, Kowlo, Andjah, Tchoo, Koini, Matchego, Okononi, Kirbi, Kowda	Anago, Djanneh, Merdeh, Matchego	Hadimidideh, Wallao, Merdeh, Djanneh, Kamani, Anago	Djanneh, Djamah
Borkou	Kirdimi	Kamaya, Kamadja, Kameryo, Toubou, Doza	Anago, Brounow, Koidji, Koïdo, Waserdo, Kourdo, Kaoulo, Palamala, Wardangado, Waserdo, Kougoudow, Kow, Koïdo, Arbibo, Bouhandjo, Kokanga, Wallao, Wardangado, Tirtido, Kourdo, Molingo, KolingadÉ, Bouhandjo, Koidji, Zalao, Milnuado, Lahandjo, Tourtoudo, Zalanga, Koukagao, Kourdo, Waserdo, Tourtoudo, Lohandji, Namanga, Sagour, Kodjibichanga, Stingado, Moulouro, Bouhandjo, KetchÉ, Aribo, Kow Manga	Wardangado, Anago, Tirtido	Waserdo, Wardangado, Memedo, Bournow, Anago	Waserdo, Bournow, Anago, Memedo
	Faya	Anakaza, Kamaya	Zalao, Anago, Brounow, Koïdo, Asandow, Kougoudow, Tirtidow, Zalanga, Mohodow, Lahandjo, Kowlow, Konsowdow, Waserdo, Mengoul, Martchano, Aribo, Memedo, Acolis, Koïdo, Arbow, Kow, Kourdao, Moittoukouli, Kowdazinga, Kownow, Meboum, Mekodi	Anago, Kougoudow, Zalao	Bournow, Arbo, Zalanga, Anago, Zalao	Anago, Brounow, Zalanga, Zalao, Kougoudow
Sahelian Zone						
Kanem	Noukou	Fizane, Kouri, Kedelia, Keria, Gourane, Gogona, Magaye, Yadad, Nagalaza	Bara, Kifi, Lia, Blatatchi, Wourdeh, Wayala, Wourdeh	Blatatchi, Wourdeh	Wayala	Wourdeh
	Mao	Kanembou, Gourane, Kogona, Bouloua, Koumborou, Touareg, Madelah	Bara, Kifi, Lia, Waleboul Dougoula, Wourdeh, Blatatchi, Wallerom, Dougoula	Waleboul Dougoula, Wourdeh	Blatatchi, Wallerom	Dougoula, Wallerom

Appendix B

List of vegetable crops, fruit crops and other crops associated with the date palm in the two zones

Zone	Department	Fruit/citrus species	Marsh and tubers	Cereals	Forage	Legume	Cosmetic species
SAHARA	Faya	Vine, Fig, Banana, Mango tree, Guava tree, Lemon tree	Carrot, beet, okra, eggplant, garlic, watermelon, melon, onion, sorrel, arugula, corchorus, sweet potato, okra, beet, tomato, cucumber, pepper, mint.	Pearl millet, wheat	Alfalfa	-	-
	Kirdimi	Vine, Banana tree, Mango tree, Guava tree, Lemon tree	Carrot, beet, okra, eggplant, garlic, watermelon, melon, onion, sorrel, arugula, corchorus, sweet potato, okra, beet, tomato, cucumber, cucumber, pepper, arugula, lettuce, potato, sorrel, mint.	Pearl millet, wheat	Alfalfa	-	-
	Ounianga-Kebir	Mango, Vine, Guava, Lemon, Fig, Olive, Grapefruit and Banana trees.	Carrot, beet, okra, eggplant, garlic, watermelon, melon, onion, sorrel, arugula, corchorus, sweet potato, okra, beet, tomato, cucumber, pepper, sorrel, zucchini, mint and cassava ...	Pearl millet and sugar cane	Alfalfa	Peanut	-
	Gouro	Mango tree, guava tree, Lemon tree, Banana tree ...	Eggplant, alfalfa, corchorus, vine, eggplant, sorrel, sweet potato, cucumber, watermelon, mint, sorrel, onion, tomato, sweet potato ...	Pearl millet	Alfalfa	-	-
SAHEL	Mao	Mango tree, Lemon tree, Guava tree, Papaya tree	Corchorus, sorrel, sweet potato, cassava, lettuce, cucumber, watermelon, okra, carrot, onion, garlic, lettuce, tomato, soil pump, cowpea, eggplant, okra, beet, sweet potato, carrot, cassava, taro, chilli, cabbage, eggplant, arugula.	Corn, Pearl millet, Sorghum, Wheat ...	Alfalfa	Peanut, cowpea	Henna
	Noukou	Mango tree, Guava tree, Paper tree, Lemon tree, Banana tree	Onion, garlic ,manioc, okra, sorrel, carrot, lettuce, eggplant, cabbage, pepper, tomato, cabbage, okra, sorrel, carrot, eggplant, pepper, manioc, cucumber, watermelon, corchorus, melon, arugula ...	Corn, Sugar cane, Wheat	-	-	Henna

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