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An Analytical Study of *Vitellaria paradoxa* C.F. Plant Which Grows in Southern Chad

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Abstract

Shea (*Vitellaria paradoxa* C.F. Gaertn.) is a flagship tree of the Sudanian-Sahelian savannas of Africa, used since the Neolithic for its nutritious fruits and multipurpose butter with food, cosmetic, and medicinal applications. Its natural distribution spans from Senegal to Sudan, including Chad, where it occurs in several provinces and local morphotypes, reflecting high intraspecific diversity. The tree has a long lifespan and slow reproductive cycles, making populations vulnerable to anthropogenic and ecological pressures. The seeds, rich in lipids (oleic and linoleic acids) and bioactive compounds (triterpenes, sterols, phenols), are exploited for shea butter and soap production, as well as traditional medicinal uses. Leaves, bark, and roots also exhibit recognized medicinal properties. Morphology and anatomy of leaves, stems, and fruits reveal adaptations to drought and climatic variability. Local agroforestry practices, including conservation in village parklands and vegetative or sexual propagation, influence regeneration and population structure. Nevertheless, overexploitation, bushfires, diseases, and animal predation threaten juvenile survival and natural regeneration. Listed under CITES, shea requires integrated conservation measures combining local management, silviculture, regeneration, and domestication. Genetic studies reveal introgressions and hybridizations among populations, emphasizing the need for research on genetic diversity and phylogeography to support sustainable management and socio-economic valorization. In conclusion, *Vitellaria paradoxa* is an ecological, economic, and cultural pillar of African savannas, whose conservation depends on scientific research, sustainable agroforestry practices, and active community engagement.

Keywords

Vitellaria paradoxa, Tropical Forest, Sudano-Sahelian, Bioclimate, Physiognomical and Shea

1. Introduction

The fruit of the shea tree has served as a traditional food source in Africa since the Neolithic period. It contains nutrients that have long been recognized for their health benefits. The thin mucilage surrounding the nut, which constitutes the fruit pulp, is composed of approximately 5% gum and 95% water. During traditional shea butter extraction, this mucilage is removed with water and left to ferment for 4 to 7 days. Due to its high gum content, the mucilage can yield a hydroalcoholic gel with an alcohol concentration of 30% to 50% (V/V), suggesting its potential as a base for the preparation of hydrosol-alcoholic and/or hydroglyceric gels [1]-[4].

The shea tree, *Vitellaria paradoxa*, occurs in a belt extending from 15˚N to 15˚S latitude, spanning from the Atlantic coast to the Abyssinian Highlands. The fruit consists of yellow pulp enclosing a sub-elliptical nut, which is protected by a hard and brittle shell. This shell, occasionally covered by a thin mucilage layer, safeguards the single almond within. The outer part of the fruit accounts for more than 60% of its total weight, while the dry kernel which contains five shea butter pulses enveloped in a thin membrane represents less than 20%. On average, the shea butter pulp constitutes 35% of the dry kernel, 40% of which is composed of lipids (54% linoleic acid, 34% oleic acid, 6% stearic acid, and 3% palmitic acid).

The life cycle of *V. paradoxa* is prolonged and characterized by two significant periods related to predation and the provision of forest fuel. The species is considered endangered, and international conservation programs recognized by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) impose trade restrictions on its fruits and nuts [5]-[7].

In Chad, *V. paradoxa* is naturally distributed across the Sudanian savannas, occurring in seven of the country's twenty-three provinces [8]. In Mandoul Province, six distinct shea tree morphotypes have been identified, and their diverse local-language names reflect a considerable level of intraspecific variability [9].

1.1. Background and Significance

Shea nut butter, or shea nut oil as it is commonly referred to, is derived from the seeds of the shea tree. It is a highly valuable plant product renowned for its medicinal, pharmacological, and cosmetic properties. Shea butter is an edible, high-value commercial fat extensively utilized by the food, cosmetic, and pharmaceutical industries. In its natural state, it is pale yellow and possesses a smooth, buttery texture. Shea nuts are a highly sought-after resource in the savannah woodlands of northern Ghana, where the poorest rural households rely on them directly and indirectly for seasonal food security, nutritional benefits, and income through the traditional processes of harvesting, processing, and trading nuts during the lean season. The high nutritional content of shea butter renders it suitable for subsistence consumption, selective and diverse agro-processing applications, as well as non-food uses such as soap production and non-edible fats for local and international markets [10]-[13].

The *Vitellaria paradoxa* tree, commonly known as the shea tree, is one of the most economically significant species within the family Sapotaceae. It constitutes a major component of the savannah woodlands of northern Ghana, where it often serves as a structural climax species. The shea tree exhibits a broad distribution across the semi-arid savannah zones of Africa, including West Africa (ranging from the sub-Sahel through the Sahel savannah to the semi-deciduous and moist savannah regions), East Africa, particularly Ethiopia, and Central Africa, notably in the Sudan zone of Uganda, Sudan, Chad, and the Democratic Republic of Congo [14].

1.2. Objectives of the Review

This review aims to synthesize current knowledge on *Vitellaria paradoxa* C.F. Gaertn. in order to support its sustainable management and conservation in Sudano-Sahelian agroforestry systems, with particular emphasis on Chad. Specifically, this review seeks to: 1) Clarify the taxonomic status and nomenclature of *Vitellaria paradoxa* and related taxa using integrated morphological and molecular evidence. 2) Summarize morphological, anatomical, and phenological characteristics of the species and their variability across ecological and geographical gradients. 3) Analyze the geographical distribution, ecological requirements, and habitat preferences of *V. paradoxa* throughout its African range. 4) Evaluate population structure, regeneration dynamics, and genetic diversity in relation to anthropogenic pressures and habitat fragmentation. 5) Review traditional uses, chemical composition, and bioactive properties of the species, highlighting their socio-economic, medicinal, and industrial importance. 6) Identify major threats and conservation challenges and discuss management, domestication, and research perspectives for the sustainable valorization of *V. paradoxa* [14]-[19].

2. Taxonomy and Nomenclature

Taxonomy The shea tree, *Vitellaria paradoxa* C.F (family Sapotaceae), is one of the most valuable Afrotropical forest trees because of the multitude of products that are derived from it and the income creating their sale provides. Persons living in the shea area benefit directly by collecting shea fruits, extracting the highly esteemed shea butter, and using products manufactured from this raw material. Business people in Ghana earned 5 million USD in one year exporting the value-added product. This high throughput of the wildcrafted sheanuts endangers (**Photo 1**) the developing regeneration process, which is further hampered by both elephant impact and related human protection activities that gradually reduce the surviving shea trees into isolated grown old trees. Three varieties of shea trees have been recognized [20]-[24].

Morphological and biochemical studies of shea trees have succeeded in differentiating *Vitellaria paradoxa* C.F. from *Vitellaria paradoxa* var. nilotica and the indeed different species Vitellaria cinerea. The used morphological and melting curve analyses are overcome in this study by combining morphological, microsatellite, and DNA barcoding studies. The results show that: 1) tree morphology illustrates three different species, whereas the analyzed samples, which originated from the entire shea tree distribution range, did not; 2) microsatellites indicate only two different groups that can be linked to their original distribution range with c. 96% match. In contrast, DNA barcoding provides a 100% correct insight into each sample [8] [15] [25] [26].

Photo 1. *Vitellaria paradoxa* seeds.

2.1. Botanical Classification

The shea tree, broadly distributed in African countries (**Map 1**), is a dominant species in the parklands agroforests of the Sahelian zone where unique socio-ecological characteristics are exhibited. In the Sudanian savannah zone, parklands are found in rich agricultural systems in Western Africa. This tree species is important to rural populations primarily because of the high-quality fat (olein and stearin) it produces, from the seed, which has been used for generations in both the pharmaceutical and cosmetic industries. The shea tree is also used as fuelwood (twigs and branches), for cellar construction (beds, chairs), for medicinal purposes, for perfumery (smell of flowers), for the manufacture of fans and boxes, and for fodder during the dry season when other herbaceous vegetables are scarce. The bark and roots are used to treat wounds, cough, and scabies, while other parts of the tree are used to treat diarrhea, dysentery, and jaundice [27]-[29]. *Vitellaria paradoxa* C.F. Gaertn belongs to the family "Sapotaceae" and has many vernacular names throughout its distribution area including the shea butter tree, shea tree, bambouk butter, butter tree, galam butter, gure, karate, karite, or lulu. The genus Vitellaria is presented in the form of a tree or a large shrub. Leaves of V. paradoxa have distinctiveness: they are short petioles (10 - 20 mm), leathery, glabrous on both surfaces, with a distinctive leathery feel. The flowering period for V. paradoxa starts from November to December and ends in April/May, depending on areas. The fruits (**Photo 2**) are mainly present in the rainy season (April-May). In Ivory Coast, the flowering cycle ranging from fruit set to maturity has been determined between 3 - 4 months [30]-[32].

Photo 2. The fruits of *Vitellaria paradoxa.*

2.2. Historical Nomenclature

The names *Vitellaria paradoxa* and formerly *Butyrospermum paradoxa* come from the butter which is the most important part of the seed and mostly used for food. Its German name "Shea-butter" (**Photo 3**) was subsequently used for the whole tree by the German botanist Heinrich Friedrich Link (1767-1851) in 1841. In 1927, a commercial pharmacist Karl Hugo Stahl from Schwelm (Germany) published a book about medicinal and aromatic substances from the tropics. He reorganized the species *Spongilla brunnea*, from the common American curassow and the mollusks of the South Sea, the so-called "pearl" and the "mother-of-pearl". In these examples, substances have been extracted, namely unknown but similar to glycerol, pelargonic acid, and arachidic acid. Stahl was especially interested in isolating the glycerides of the volatile fatty acids from the seed fat of *Butyrospermum* (Vitellaria) *paradoxa*. He recommended the refined stones of the fruits for decoration purposes and for grinding the fat to prepare finger- or shoe-cream. And if the fat alone was used, its application as an ointment for the hair.

Photo 3. Butter of *Vitellaria paradoxa.*

3. Morphology and Anatomy

In the submersion zone, wavy guard cells are present only in the lower submersion. More than 90% of the cells are often surprisingly living. In the water zone, the cells display a tight disposition, without an aeration site, with two rows of chloroplasts along the anticline wall, except in dicotic and tricotic regions where the facultative anastomosis is localized. The trait differences found in Vitellaria are indicative of a strategy of sympodia development, which permits economic use of the resisting water loss resource and the carrying out of photosynthesis every time that confidentiality becomes possible, under the new development of mesophyll tissues resulting from vacuolar turgescence [33] [34].

The leaf is symmetric at first and then becomes dissymmetric, with a dense but alternating ventilation system in the upper wing. In the wavy dorsal wall, flat cells are disposed in parallel and display two distinctive row discontinuities in the direction of the submersion. However, the depth of cells is identical and the upper part of the two discontinuities is superimposed. The discontinuities facilitate cellular suction while the air conduit is completely filled with water [35] [36].

The morphology and anatomy of shea trees (*Vitellaria paradoxa*) were studied in the field, with the help of literature and in the Department of Biological Sciences of the University of Ouagadougou, Burkina Faso. The petiole of *V. paradoxa* is characterized by a canaliculate midrib beneath, glandular at its adaxial face at the base of the upper blade and leafsheath. The vascular system is continuous, forming arcs from which simple sclerenchyma of the cylinder is separated by the midrib [37] [38].

3.1. Leaf Structure

Internal anatomical investigations of *Vitellaria paradoxa* revealed multiple structural levels that are essential for understanding its growth and functional morphology. These include the organization of vascular tissues, the structure of stems and branches, and the micro- and ultrastructural organization of leaves. Leaf anatomy encompasses the epidermal cells, cuticle thickness, stomatal type, mesophyll differentiation, chloroplast abundance, and chloroplast ultrastructure. Additionally, the ontogenetic and biomorphological development of young shoots is closely linked to the activity of apical and axillary meristems. Young leaves are initially arranged in a vertically oriented pattern; however, the developing leaf lamina and petiole remain deeply embedded within the shoot tissues during early stages of growth. Longitudinal sections of the shoot show a well-organized short-shoot zone, displaying spiral phyllotaxis of small leaves and the formation of grape-like fruits characteristic of the species [39] [40].

In natural conditions, young shoots are easily recognizable by their bright red foliage. Leaves are regularly arranged along branchlets, and new leaves emerge from both apical and axillary buds. Each leaf consists of a petiole of variable length attached to the lamina, which differentiates into epi- and hypophyllous tissues. Variations in lamina thickness are mainly due to folding during development. Epidermal cells are elongated with thick cell walls, and their outer periclinal walls are covered by a distinct waxy cuticle. Stomata are paracytic. The mesophyll is homogeneously developed, and chloroplast numbers increase progressively as leaves mature. These anatomical features contribute to the species' adaptability to the

Sudano-Sahelian environment and its ecological success [40].

3.2. Fruit Characteristics

The fruit (**Photo 2**) is a woody, spherical drupe, measuring 2.5 - 4 cm in diameter, with an average weight of 5.6 g. Overripe fruits become deeply fissured and turn brown. The epicarp is smooth, featuring a short longitudinal furrow at the distal end, opposite the point of attachment of the silique to the supporting branch. The mesocarp (fleshy layer) is approximately 1 mm thick, dark brown, and contains latex that develops unique properties a few minutes after exposure, exhibiting exceptional tenacity for soap and foam. The endocarp of the silique is longer than it is thick. Both the endocarp and the testa are very brittle, dry, hard, woody, and exhibit an outward curvature.

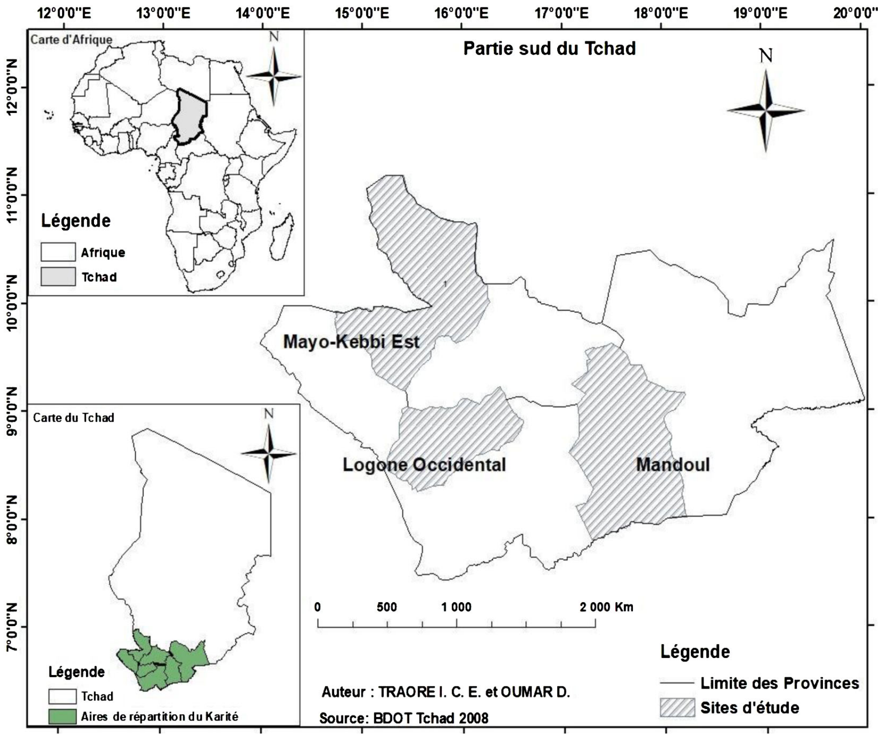
The seeds (**Photo 1**) measure approximately 1 × 2 cm and constitute 9% - 16% of the total fruit weight. They are ovoid, with a pronounced dorsal furrow extending almost the entire length of the seed, and a corresponding ventral protuberance. The apex is rounded, and the base is concave, oriented toward the funicle. The testa is brown and woody. Upon drying, the seeds should be sown at a shallow depth, preferably in shaded conditions, and in soil enriched with organic matter [8] [19].

4. Distribution and Habitat

The population of *Vitellaria paradoxa* in Chad is generally associated with *Dacryodes buettneri*. The region's bioclimatic diversity provides a wide range of eco-edaphic conditions, shaping plants that are physiognomically distinct from the potential natural vegetation and the Sudanian plant community. This heterogeneity also supports significant biological diversity by creating highly specific biotopes. A field study was carried out in the provinces of Mayo-Kebbi East, Logone Occidental, and Mandoul, within Chad's Sudanian zone (**Map 1**). The area offers favorable conditions for *Vitellaria paradoxa* growth, characterized by diverse climatic and environmental parameters (**Table 1**) [41]. The climate of these phytogeographic units is sub-Saharan, with a Sudano-Sahelian wet pattern and dominant thermal aridity, influencing vegetation differentiation across the landscape.

The identified bioclimatic stages, based on Stefania (Davies), and the *Vitellaria paradoxa*-bearing units, help explain the effects of landscape polymorphism on the dominant Sudano-Sahelian syntactic association, including its life cycle and vegetation physiognomy (**Map 1**) [8] [42].

Vitellaria paradoxa occurs throughout the Sudanian zone in two main phytogeographic units, between 17˚ - 18˚ East longitude and 8˚ - 13˚ South latitude. It forms a continuous band from West to Southeast Africa, spanning Mali, Côte d'Ivoire, Ghana, Togo, Benin, Nigeria, Chad, and Cameroon, known as the Baoulé belt (**Map 2**). A secondary massif is located in northwestern Burkina Faso, near the Mali border [42] [43].



Map 1. Geographical distribution of *Vitellaria paradoxa* in Chad.

Table 1. The environmental characteristics of the three study sites.

Settings	Provinces		
Environmental	Mandoul	Logone Occidental	Mayo-Kebbi Est
Geographic coordinates	8˚54'36"N, 17˚33'00"E	8˚42'0"N, 15˚52'60"E	10˚16'N, 15˚22'E
Rainy season	Avril-octobre	Avril-octobre	Mai-octobre
Average rainfall	821.8 mm.	1127 mm	606.9 mm.
Average temperature	28.4˚C	28.9˚C	28.9˚C
Network hydrographic	Bahr Sara	Logone, Lac Wey, Lac Taba	Ba-Dli
Soil types	Sandy lateritic or ferralitic and clayey-silty	Ferralitic and ferruginous, clayey-sandy and silty	Sols hydromorphes, Vertisols
Types of vegetation	Tree savannah	Tree savannah	Shrubby savannah

4.1. Geographical Range

The geographical range of V. paradoxa is mainly distributed in the Sahelian and Sudanian zones such as Senegal, Burkina Faso, Mali, Guinea, Guinea Bissau, Sierra Leone, Ivory Coast, Ghana, Togo, Benin, Niger, Nigeria, Cameroon, Chad, South Sudan, Central African Republic, and Sudan (Map 2). The shea tree potential in Chad is mainly concentrated in the southern part of the country. As shown in Table 2, the survey of 4,258,819 hectares made it possible to inventory 92,683,130 adult shea trees. This inventoried area represents approximately 30% of the total surface area of the seven administrative regions where the species occurs naturally in Chad [8].

It is rarely found in the high rainfall Guinea zone. Moreover, V. paradoxa also extends to some areas in the adjacent zones, such as the sub-Saharan region, Ethiopia, Uganda, Kenya, Tanzania and Somalia in East Africa, Mozambique and Madagascar in South Africa, and Gambia, Cabo Verde, Late Cote d'Ivoire, and Uganda. The most extensive distribution area is located in the belt along the 9th parallel of the northern latitude of the African continent. It stretches over 5500 kilometers from the west to the east and from the north to the south at latitude 13o N to below 5o N. A few people even devoted their entire lives to researching it, so they are recognized as an expert in the field of V. paradoxa (**Map 2**) [44]-[46].

Map 2. Geographical distribution of *Vitellaria paradoxa* in Africa.

Table 2. Estimated shea potential by region in Chad.

Region	Area(ha)	Area considered (ha)	Density Moy./ha	Number shea	%
Mayo Kebbi Est	1,822,527	364,505	0 ± 8	2,916,043	9
Mayo Kebbi Ouest	1,283,533	256,707	0 ± 12	3,080,478	10
Tandjilé	1,753,624	584,541	0 ± 16	9,352,661	12
Logone Occidental	884,542	294,847	1 ± 18	5,307,251	10
Logone Oriental	2,364,238	788,079	2 ± 22	17,337,746	18
Mandoul	1,732,664	577,555	2 ± 32	18,481,741	12
Moyen Chari	4,177,754	1,392,585	1 ± 26	36,207,204	29
Total	14,018,882	4,258,819	1 ± 19	92,683,130	100

4.2. Ecological Preferences

The village-owned and protected area managed farmland appear as ideal forest-parklands configurations for this species' sustainability. The park growth does not seem to have negative effects on the tree regeneration. The population genetic approach showed that the observed habitat fragmentation would represent an increase in the genetic distances between populations, which may exacerbate in the future, the remnant due to loss of genetic diversity. The survey done before the silvicultural approach showed that the village inhabitants are involved in the kernel harvesting process, without helping the tree managers in the silviculture. Quotas to support the villagers and penalties to avoid any collective sanctions are associated conditions. Biologically rich ecosystems like the parklands, which maintain a high number of rare species, are compromised [47] [48].

Vitellaria paradoxa C.F (Sapotaceae) is a guide flora species of our bush-parklands, and our group of interest is doing monitoring of its status. Unfortunately, there are few studies about this species for guidance in this approach. The second chapter of the thesis is devoted to its different aspects: the ethno-botanical uses, the genetic diversity, the regeneration, and the silviculture in order to have a comprehensive state of African parklands. The studies preceding the approach about the kernel use an old population data. The analysis of the recruitment of more than 500 populations data allowed us to know the species' demography and the factors of its regeneration. Six percent of only the populations show a normal pyramidal structure; the populations area of village-owned farmland (place without logging) is significantly higher than those made taxa which are least abundant. The silviculture chapter is established without the large scars situation; the common techniques of regeneration are diverse with the main informal tools.

5. Traditional Uses

When you see the shea tree growing in its typical Sudano-Sahelian range, with its elegant fruit and leaves, it is often considered an important symbol of the fragile environment of northern Ghana, for which women and poor inhabitants of this area have developed an astounding knowledge and use of the surrounding environment to address their basic needs. Inhabitants consider the tree an invaluable resource during long dry seasons when other food crops may fail, and for many centuries have appropriated this nature's gift, which they harvest and manage sustainably. This case study paper is the result of the development of a socio-economic network project initiated by the European Union, called the "Socio-Ecological Development of Sudan-Sahelian Africa" (SEDESA) project [49] [50].

The products derived from an African tree, *Vitellaria paradoxa*, the shea tree or karate butter tree, which is found in the Sudano-Sahelian area of Africa, in the dry savanna and thickets, are widely used. This tree produces some fruit rich in fat which is used as a source of edible oil and in many other applications by local people. The potential of the shea tree to contribute to poverty reduction is receiving increased attention from a number of interested parties including international institutions, non-governmental organizations (NGOs), and academic institutions. An increasing emphasis is being placed on the non-timber forest products (NTFPs) in the development planning, and research and development programs. To exploit responsibly and sustainably the full potential of this natural resource, it is important to understand the biology, ecology, and uses of V. paradoxa [51] [52].

Medicinal Applications

The stembark is used to treat fever, in smallpox treatment, for coughs, sores, sore throats, and as a general tonic. The root decoction treats pneumonia, the roots are chewed and the extract is applied on cuts or sinus, the bark and the leaves are chewed for the treatment of migraine, the twigs are chewed for cleaning teeth, the bark decoction used as a wash for edema, rheumatism, and as well as a tonic in liver disease and also in dysentery, enlarged spleen. The leaves are used to treat madness, women after expulsion are treated with macerated leaves in Somano and Dosso, the leaf powder is taken for liver complaints, gastrointestinal problems, and lumbago. The leaves are also used to heal fractures and as an enema. Subtribes and a small amount of shea butter are used in preparing Shea margarine. Some members of the other genera in the Butyrosperminae—subtribes and of the Butyrophyllinae—subtribes are also used in the treatments of various diseases. The members of subtribes to which Vitellaria belongs generally display stronger effects than those of other taxa [53] [54].

Several traditional remedies are prepared from different parts of the shea tree in many parts of the African continent. It is believed to have numerous medicinal properties and has been used in the treatment of various diseases and illnesses. It is used in the treatment of injuries, colds, bodily pains, skin diseases, rheumatism, as treatment during pregnancy, for chest infections, gastrointestinal disorders, diarrhea, coughs, headache, mouth diseases, as an antioxidant, antimicrobial activity, anti-inflammatory activity, and anti-hypertensive effect. The seeds are used to make black soap, which is used in the treatment of various skin infections like eczema, ringworm, and some bacterial skin infections. The black soap is also used for hair growth, hair run-down, and for keeping the hair moist. The powdered bark is a popular ingredient in preparing Balanite teeth-cleaning sticks. The shea fruits are used as a feed additive in poultry feed to maintain and enhance the flavor and color of the egg yolk of ducks and chickens [13] [55].

6. Chemical Composition

Triterpenic substances occupy a special place in the composition of the unsaponifiable fraction of the karite oil. 25 components of this group were detected through the gas-liquid chromatography method, among them lupeol of 39.4% content along with 13,23-dimethyl triterpenic alcohol. In the seed of vitellaria, orthodihydroxy fullerenic acid and anomega dihydroxy fullerenic acid were discovered in the form of n-hexosaminates. The lipid fraction in the other water-mildly but the karite seed already contained alpha-tocopherol, while the eugomovakaint, soncol, and eurison. Proceeding from the above information, it is already possible to affirm that although non-fatty components are contained in the large amount of fruit secretions of vitellaria paradox but not unsaponifiable are the main non-fatty components [56].

An analysis of *Vitellaria paradoxa* seed components revealed different proportions of their species according to the degree of detection. To date, the main components were fats and unsaponifiable substances. Fats consist essentially of triglycerides of saturated stearic and unsaturated oleic acids and contain only small amounts of palmitic acid, linoleic acid, and arachidic acid. 17 microcomponents were detected in seed oil of karite nut, 10 of which were detected for the first time. The main microcomponent of the unsaponifiable is sitosterol, cholesterol, stigmasterol, amyrine, butolenol, and butolenolb. All the listed sterols are present in the seed of the karite, the remaining of them are present in an equimolecular amount and amount to 80.8% - 86.5% of the unsaponifiable substances of oil [6] [57].

6.1. Major Compounds Identified

Shea nuts were fat-rich, and the fat was characterized by the significant dominance of unsaturated fatty acids, six of which contributed up to 80% of the total content. All fatty acids formed an even chain length distribution. A triacylglycerol study showed the overwhelming predominance of OOO, ODO, OOL, and OLL. High amounts of phospholipids and diacylglycerols were also present. Unsaponifiables varied considerably, but the triterpene alcohols, amyrin (4) and butyrospermol (5), were the most commonly found compounds followed by α-tocopherol (3), β-sitosterol (1), and stigmasterol (2). Although a high potential to contribute to the phenomenon of off-flavors in shea butter does exist, the actual concentration of these compounds was low, and they consequently had little impact on the aroma of the butter. The total phenolic content of the nuts was highly variable, and the concentrations of seven metabolites with an antioxidant effect fluctuated between undetectable levels to 600 mg hydrophilic gallic acid equivalents/kg. Overall, the results communicated that the amounts and composition of anti-nutritive compounds in nuts depend on manifold factors which explain the variability documented in the literature [58]-[60].

The phenolic and total acid content were significant determinants of shea butter quality and impacted relevant physicochemical properties, including the nut taste, roasting time, and color of the butter. In the course of studying variations in the phenolic and total acid content of shea butter, we found that shea nuts which yielded a butter containing less than 20 mg/kg of phenolic compounds had a specific odor, a shorter roasting time, and a light-colored butter. We decided to determine the identities and concentrations of phenolic and other chemical components in shea nuts and butter. We began by examining the lipid concept of S. paradoxa nuts, the major chemical constituents of the stearin and olein fractions obtained as a result of the refining process, and the composition of the volatile fraction of the shea nut and shea butter aroma. In this paper, the results of a shea butter study are presented. The lipid composition of S. paradoxa nuts from different world countries was established [61] [62].

6.2. Bioactive Properties

Vitellaria paradoxa C.F. Gaertn. is a medicinal tree growing in the savannah and the forest region of tropical Africa. This member of the family Sapotaceae plays an important role in the life of millions of people. Three main constructed features were developed within this framework: the gum, the homoleucotannins, and the triterpene mixture. Besides these compounds, the seeds contain starch and about 20% of protein. The triglycerides are composed of about 75% arachidic acid, 5% stearic acid, 5% oleic acid, and about 1% palmitic acid. Also, in this triterpene-rich fraction, a number of esters and hydroxylated triterpenes have been characterized. The second fruits component, 4% of lipids, can form an important part be extracted with diethyl ether. This part exhibits antibacterial and antiviral activity. Two important and very unique applications from this subject are presented. The first is that the cream on the bottom was used in rural preparations for the treatment of dermatoses in cases of leather irritation. The second natural preparation with the use of the developed data is bakeries containing the *Vitellaria paradoxa* C. F. Gaertn. solid fraction [6] [63].

This work is an analytical study of the seeds of *Vitellaria paradoxa* C.F. Gaertn. (family Sapotaceae), a well-known medicinal plant found in tropical Africa. Six main groups of compounds were isolated from the seeds by extraction, fractionation, and chromatographic procedures. These were gum, lipids, triterpenes, homoleucotannins, protein, and carbohydrates. The homoleucotannins were found to be a series of di-galloyl mat of the new tri-homomeric type 1,2,3 octa-hydroxy tris-galloyl glucose (holecystoyl-glucose), together with its new diphenic acid 1,6,3,4,5 pentahydroxy tris-galloyl glucose isomer (vitolparadoic acid). All the structures obtained were characterized by physico-chemical methods and NMR spectroscopy. The seeds exhibited different plant bioactive properties like antibacterial, antifungal, antiviral, molluscicidal, antimosquito, and antistress activity. Beeswax, seed fat, and butter were used by manual workers for wood, leather, ropes, clothes, and skin treatment.

7. Cultivation and Domestication

Shea is not especially competitive and may even need some participation and protection from humans in terrains where fire has been suppressed. Plantations, often only a tree or two, are centered on the homestead, and numerous if isolated trees adjacent to the villages, are well-defined components and valued as part of the farming environment. Few wild occurring and old plantation trees had not been damaged at least once and subsequent pruning is common following it. Physical garden fences are uncommon, but living and seasonal quartering of plantations trials occurs in farming territories of high game population. Woody elements of baby leaf are often regularized around the homestead. Bush fires have a considerable influence on Shea fire because regeneration is not only from seed, which it resists by increasing dry matter root allocation, but also from damaged stems and saplings [64] [65].

A method to separate large- and small-grain individuals that is based on the physical properties of seeds might be useful in agricultural practice. The tree is sometimes cropped incidentally for construction, firewood, rations, traditional medicines and fodder for livestock although some settlers in savannah river valleys take advantage of wild occurrences by planting them along the river bank. These are usually maintained in a shrub-form stunted growth condition, urged along by periodic removal of major branches for leaves, which quite enjoys the enthusiasm of early livestock feeding pressure on these lands. The process is readily reversible, habitats passage to forest land, and in sub-Horic tree is apparent systems return are relatively easily achievable [66].

A wide experimental approach to modification of the aqueous moisture characteristics of seeds is likely to find methods of overcoming dormancy in the first day of re-activation in placing the seeds in a moderate thermally obstructed atmosphere during the evening, removal of the restrictions in the morning and after some hours cooling to room temperature. Germination manipulations are not limited to seeds, other potentially promising procedures to expedite the reactivation of seeds are water culture exposed seeds during the day and their re-activation in moderately obstructed atmosphere in the evening. Hard seed in Vitellaria largely consists of small-grain individuals effectively germinating little in the first year [67].

7.1. Agroforestry Practices

This chapter presents the first part of the investigation. Methods are presented first; practices found relating to the place of parkland fallows in local agro-ecosystems surround this arborescent plant. Crops are associated with this parkland ecosystem. Their conveyance is under scrutiny. This chapter constitutes a background that we need to highlight the maneuvering room, the availability of farmers to slightly subside their activity without overshadowing their main farming purpose. We will see in the following chapters that the availability of farmers mostly depends on the orientation of their long-term investment in parklands. They are largely different and change the way farmers work with the conveyance and diversity of cultivated plants in a park because they are not perceived and managed by farmers in the same way [68].

According to a study conducted in southern Chad, the woody vegetation associated with *Vitellaria paradoxa* is mainly dominated by the families Fabaceae and Combretaceae, due to their strong representation in the surveyed plots. The Shannon-Weaver diversity index and Pielou's evenness index indicate low species diversity and a disturbed vegetation structure, resulting from selective management practices by farmers who prioritize the conservation of useful species, particularly *V. paradoxa*. The low floristic richness is thus explained by the dominance of shea trees in the arboreal layer. Increasing anthropogenic pressure linked to the exploitation of plant resources leads to biodiversity loss and ecosystem imbalance. Furthermore, the high proportion of diseased individuals reveals the vulnerability of *V. paradoxa*, exacerbated by parasitism, epiphytism, agricultural practices (pruning, ring-barking), and bush fires, with Loranthaceae parasites constituting a major threat to fruit production and species survival [41].

7.2. Propagation Techniques

A recent study indicates an overall satisfactory regeneration of *Vitellaria paradoxa* in the Moyen Chari, Mandoul, Tandjilé, Mayo Kebbi East, and Logone Occidental regions. However, the population structure of shea stands remains unbalanced, characterized by a strong dominance of adult individuals and a low proportion of juveniles. This pattern is largely attributed to traditional management practices adopted by local communities, which favor the selection and protection of highly productive trees, ultimately leading to ageing stands. Nevertheless, the observed level of regeneration suggests that the renewal of shea populations may be ensured, provided that juvenile individuals receive adequate protection.

The main anthropogenic pressures responsible for juvenile mortality include insufficient maintenance, bush fires, and uncontrolled cutting. In contrast, the conservation of adult trees requires sustained efforts to reduce premature fruit harvesting, as well as to control parasitic infestations and phytosanitary threats. In the Logone Oriental and Mayo Kebbi West regions, however, producers implement more effective protection measures for shea trees at both juvenile and adult stages. Overall, natural shea stands display an unstable demographic structure, resulting from the limited natural regeneration capacity of this heavily exploited species and the heliophilous nature of its seedlings, which develop poorly under shaded conditions. Consequently, bush fires and intense anthropogenic pressure constitute major constraints to the successful transition of juvenile individuals to the adult stage.

Vegetative propagation of shea (*Vitellaria paradoxa*) using seedling rootstocks represents the most rapid method for producing planting material. Seed-derived rootstocks generally require three to four years before becoming suitable for grafting, whereas juvenile saplings may be ready for vegetative propagation after only one year of growth. Vegetative propagation is seasonal and is typically carried out between late January and late March. Grafting techniques such as cleft grafting and saddle grafting have proven effective. Successful establishment in parkland systems depends on maintaining cuttings under regular irrigation, often in basins located beneath tree canopies during spring, when active shoot growth occurs. Root system development may extend over more than one year. Additional propagation techniques include embryo culture on artificial substrates, such as coconut-based media, as well as in vitro propagation through tissue culture, which can be used to enhance multiplication rates under controlled conditions [6] [69].

8. Conservation Status

Vitellaria paradoxa is a species present only in some countries of the African Sudano-Sahelian zone. Demands for its shea fruit, its oil, and Ghana, one of the most important processing and export countries of Burkina Faso, are experiencing depletion of their shea resources. Despite several studies already carried out on the species, little information remains on the conservation status and phenology according to the population or the biogeography. Our study will contribute to a greater characterization of this very important species of the Sudanian bloc for efficient management [18] [70].

An analytical study of *Vitellaria paradoxa* C.F. Gaerten was carried out in two localities of central-western Burkina Faso, Boussé and Saponé. V. paradoxa is mainly present in humid and sub-humid types of vegetation. The characterization showed differences but also common features at the morphological, phenological, and structural levels. A high density of young seedlings is recorded per population. The demographic structure of populations represents the influence of human pressure (tapping) and the ecological area (fragmented forest). Biometric studies are variable following the locality. Commanding a local and economic interest, *Vitellaria paradoxa* subsp. paradoxa is in abundance. The threat on populations is mainly anthropic. Given the importance of the species and the current threats, conservation measures are urgent and could take place through the management of the stands, the activity of production of the villages, reforestation, and rotations of use by the regional authorities [16].

The diameter class structure reveals a low proportion of young individuals, indicating disturbed stands of *Vitellaria paradoxa* and a low regeneration potential. The absence of small-diameter individuals and the irregularities observed in the upper classes reflect difficulties in renewal and in the transition between developmental stages. This situation is mainly linked to natural and anthropogenic disturbance factors such as overgrazing, bush fires, recurrent droughts, agricultural practices, and intensive fruit harvesting. High seedling mortality and unfavorable climatic conditions compromise the survival and regeneration of the species, confirming its vulnerability in shea parks [41].

8.1. Threats and Challenges

Climate change could be another risk model. Until now, no risk evaluation has been conducted that allows for providing precise background information for model calculations. If one just takes the less heavy rainfalls over larger areas into account, the prospects for the continuance of habitats where the species are rare or very rare appear highly precarious. High land fertility and a lower diversity of species coexisting with *Vitellaria paradoxa* by sharply defined species borders emphasize the recreational use of the soil nutrient resources. The reduction of the species trade or the elimination of the species by forest replaced by arable acreage and suppression of habitats lead to species substitutions. In small or highly fragmented clusters, the gathering often leads to depletion by vast-scale earth excavation, therefore making a continued subsidy in traditional karité products and markets no easy task. Because neighboring communities were never used to paying for a product they have access to, they opt to sell on highly accessible or frequently visited markets [71] [72].

The economic and traditional importance of *Vitellaria paradoxa* is put under pressure by various factors. On the one hand, it faces severe threats and challenges in several of its distribution ranges. On the other hand, it has to cope with the loss of a significant number of alleles. Deforestation, high logging rates, and mismanagement have led to a lack of tree regeneration in large areas. Furthermore, in various places, illegitimate annual clearance or protection of traditional parklands are practiced, resulting in the clearing of areas that should lie fallow as bush fallows in order to avoid soil exhaustion. The loss of juvenile plants due to the abundant harvest of seeds has an important effect, particularly with unsupervised open collection. Furthermore, inadequate or uninformed treatment of trees during or after seed collection endangers the growth of trees. Attack by Phytophthora megakarya (fungal disease) leads to the death of young, easily accessible trees [73].

8.2. Conservation Efforts

Conservation strategies were investigated through the identification of the diverse, complex, and situational institutions and decisions influencing *Vitellaria paradoxa* access and management. Only weak management systems could be discovered to protect or regulate the tree in several regions. Furthermore, there was ambiguity over tree-specific land tenure authority and user rights, which only posed authoritative use and availability of the tree. Several adjustments can be made to improve the situation. Tailored strategic results aim at the development of realistic and sensitive conservation policy through local culture-based, people-, eco-specific, and long-term maintenance of indigenous trees. Alternatives to current management focused on a holistic, normative conservation model, emphasizing sociocultural, ecological, and economic factors. RTAL dissemination can play a crucial role in the development of innovative management regimes [6].

Concerns over indigenous tree management and dwindling stocks of *Vitellaria paradoxa* fruits have intensified in recent years. The species has lost substantial ground to food crops, operates as a common-pool resource, and has continuously failed to renew itself in several regions. In terms of threats to the tree, eight major causes were identified, attributable to both natural factors and human use. Findings suggested a revision of current conservation policy since exploitation of the species has intensified, together with commercial values of its by-products [73] [74].

9. Genetic Diversity and Research Perspectives

Furthermore, the analysis of a given study indicates that the two ecotypes of *Vi-*

tellaria aim to assess the genetic diversity of the species and to improve understanding of the constraints related to its domestication and management. Nearly one third of the COI sequences and approximately half of the ITS sequences derived from wild trees appear to correspond to introgressed forms. Four accessions of *V. paradoxa* collected outside its natural range of distribution, yet belonging to well-established reference units, exhibit DNA fragments from *Vitellaria nilotica* and *Rosa hirtula*. These genetic components may have been acquired through backcrossing or other hybridization processes, a phenomenon likely to intensify with the expansion of anthropogenic and transformed habitats.

According to the same author, several future research directions concerning *Vitellaria paradoxa* focus on its geographical distribution. While substantial data have been collected in West, East, and Central Africa, information remains scarce for Gabon, and some available results are contradictory with respect to the species' range. Certain hypotheses suggest that *V. paradoxa* originated in Cameroon and subsequently migrated to other regions. Other theories, supported by evidence related to past glaciations as well as by phylogenetic, phylogeographic, and phenotypic variation analyses, have led foresters to recommend comprehensive experimental studies to resolve these biogeographical uncertainties. In this regard, the Gabonese hypothesis warrants rigorous experimental investigation [75].

Dynamics of Shea Tree Populations

Changes in the shea populations of Burkina Faso were monitored using news magazines and assessment reports over a five-year period. 87% of all studied populations showed no significant change in the number of fruit-bearing populations. In seven populations, extinction risk was between 20% and 98%. Only one of two populations with regeneration under remaining heaviest poles seemed to be stable. The other population with previously detected seedling establishment had lost many young trees because of cattle poaching and trampling damage. High loss rates of living configurations after the establishment of shear parks have also been documented in northern Burkina Faso when potentially suitable soils were protected from poaching. In conclusion, on unprotected land, the fear of the tree's extinction may be responsible for communication and field policy that regard shea here as a "mainly use" forest species. Even shea management manuals highlight park establishment and ignore any other form of land use. Instead of excluding grazers or anthropogen growers, the implications for agroforestry systems as part of land management plans are neglected. With the present information, a general recommendation, especially for shea knowledge public outreach, for advising shea conservation by park establishment is not justified [76].

The production of shea butter is a major biotechnological application of the shea tree. This natural fat, extracted from the kernels of the fruits, is used for edible and non-edible applications, such as cooking, soap making, and candles. Extractive use of the fruits and leaves of the tree causes heavy pressure on it and has often been suggested as a reason for its depletion. On the other hand, studies have shown that focus on these products alone causes large annual losses in income that far exceed the cost of conservation and plant establishment. Conservation of the trees generally goes along with the establishment of artificial shea parks or natural regeneration on farms, and includes establishing a number of seedlings under living tree covers. Empirical studies on the long-term stability of such systems are lacking, and therefore, conservation efforts may be counterproductive and detrimental to the local economy and the people depending on shea [6] [77].

10. Conclusions

This review highlights the multidimensional importance of *Vitellaria paradoxa* C.F. Gaertn, a keystone species of Sudano-Sahelian agroforestry systems and a major socio-economic resource for millions of rural households, particularly in West and Central Africa. The synthesis of taxonomic, morphological, anatomical, ecological, genetic, and ethnobotanical information confirms the biological complexity of the species and the pronounced variability of its populations along ecological and geographical gradients.

Recent advances in taxonomy, integrating morphological traits with microsatellite markers and DNA barcoding, have helped to clarify the systematic status of the genus *Vitellaria* while revealing genetic structuring closely linked to its geographical distribution. Ecologically, *V. paradoxa* is strongly associated with Sudanian parklands, where it plays a fundamental role in maintaining biodiversity, soil fertility, and the resilience of agricultural systems under increasing climatic stress. However, most stands exhibit unbalanced demographic structures, characterized by a dominance of mature individuals and limited natural regeneration, largely due to anthropogenic pressures, such as bush fires, agricultural practices, overharvesting of fruits, and parasitic infestations.

The wide range of traditional, medicinal, nutritional, and industrial uses, together with the remarkable chemical composition and bioactive properties of shea butter, underlines the strategic value of the species for local livelihoods, food security, and the pharmaceutical and cosmetic industries. At the same time, increasing commercialization and unsustainable exploitation intensify the risks of population decline and genetic erosion, particularly in areas where management and conservation frameworks remain weak or poorly enforced.

Overall, the findings emphasize the urgent need for integrated and context-specific management strategies that combine in situ conservation, enhancement of natural regeneration, domestication and propagation efforts, secure land and tree tenure, and the active involvement of local communities. Further research is required to address remaining knowledge gaps, especially concerning population dynamics, fine-scale genetic diversity, climate change impacts, and the optimization of vegetative propagation techniques.

In conclusion, the long-term sustainability of *Vitellaria paradoxa* within Sudano-Sahelian agroforestry systems, particularly in Chad, will depend on the ability to reconcile economic valorization with biodiversity conservation and the preservation of indigenous knowledge, within a coherent and durable development framework.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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