PROVENANCE VARIATION FOR MORPHOLOGICAL TRAITS AND OIL CONTENT IN SOME *Jatropha curcas* L.

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BY

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DEPARTMENT OF PLANT SCIENCE,
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MARCH, 2014

DECLARATION

I declare that the work in this thesis entitled **"Provenance Variation for Morphological Traits and Oil Content in Some *Jatropha curcas* L.''** has been carried out by me in the Department of Plant Science. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other Institution.

Usman, Muhammad	Signature	Date

CERTIFICATION

This thesis entitled ‘’**PROVENANCE VARIATION FOR MORPHOLOGICAL TRAITS AND OIL CONTENT IN SOME *Jatropha curcas* L.’’** by Muhammad USMAN meets the regulations governing the award of the degree of Master of Science in Plant Breeding of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This work is dedicated to my parents Malam Usman and Hajiya Fatima, my wife Hajiya Khadiza and my children Fatima, Abdurrahman, Faisal, Ibrahim, Salim, Samir and Ahmad

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ABSTRACT

Twenty one provenances of *Jatropha curcas* L. collected from seven states of the Northwestern Nigeria and established in a provenance trial at the Institute for Agricultural Research farm, Samaru, Ahmadu Bello University, Zaria, Nigeria were evaluated using Principal Component Analysis (PCA), Rank Summation Index (RSI) and Genetic Distance (GD) to analyze their pattern of variation, identify the major traits responsible for their variation and suggest appropriate breeding materials to improve the crop. Ten plants were randomly selected in each provenance and evaluated for nine morphological traits and oil content. All the provenances showed highly significant variations except main stem height, which was significant at 0.05 level of probability. Mean performance showed significant differences for all traits with each trait exhibiting a considerable range. Higher genotypic than phenotypic variances were observed for plant height, number of branches on collar, number of lateral branches, number of capsules per lateral and oil content. However, these traits have low genotypic coefficients of variability indicating low range of genetic variation. High heritability estimates were observed for plant height, number of branches on collar, number of capsules per lateral branch and oil content. Three out of the ten principal components extracted had eigenvalues > 1 and altogether accounted for 77.07% of the total variability. Principal component 1 exhibited 34.77% while principal components 2 & 3 showed 24.48% and 17.83% variability, respectively among the provenances for the traits studied. From the associated eigenvectors, Principal Component 1 is associated with number of fruit bunch per lateral, number of capsules per bunch and number of capsules per lateral branch. Collar height, collar thickness and number of branches on collar were important for principal component 2. The third principal

component however, was more related to plant height and main stem height. The PCA therefore, discriminated and separated the 21 provenances in terms of collar traits, bunch traits and height traits indicating them to be the major traits responsible for the variation in the *Jatropha curcas* L. provenances. Based on RSI, IARJAT200901, IARJAT2009039 and IARJAT2009036 obtained from Soba, Gwarzo and Ruwan Kanya provenances were the best materials in terms of plant height, number of lateral branches, number of fruit bunch per lateral branch, number of capsules per bunch and oil content. These accessions are therefore considered the best potential materials for the improvement of *Jatropha curcas* L. in Nigeria. However, considering the high GD between accessions IARJAT200901 and IARJAT2009039 obtained from Soba and Gwarzo provenances (9.15), and the result from PCA, a cross between the two accessions is recommended.

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CHAPTER ONE

1.0 INTRODUCTION

Jatropha curcas L., a multipurpose, drought resistant, perennial plant belonging to *Euphorbiaceae* family is gaining lots of importance for the production of biodiesel (Ashwani and Satyawati, 2008). The genus *Jatropha* is one of the prospective oil yielding tree crops. It is a morphologically diverse genus comprising 160-175 species (Dehgan and Webster, 1979). *Jatropha curcas* L. is a drought-resistant perennial, growing well in marginal/poor soil, easy to establish, grows relatively quickly and lives, producing seeds up to 50 years (Henning, 1998). It's ability to grow on marginal, waste or arid land without displacing food crops that is perhaps of most potential importance to the developing countries like Nigeria and its effects on climate change (Kabir, 2009). Common names include Barbados Nut, Purging Nut and Physic Nut (Anon., 2009). It is a deciduous tree or shrub which produces seeds rich in toxic oil (27–40%) that can be extracted easily with techniques of different sophistication levels (Achten *et al*, 2007). The crude Jatropha oil meets the fuel quality standards of rapeseed and can be easily converted into biodiesel, meeting US and European standards (Wouter *et al*, 2010). Jatropha is used as a hedge (living fence) all over the world by farmers as it is not browsed by animals (Garg*et al*, 2011). Jatropha has evoked interest all over the world in comparison to other tree-borne oil seed crops because of its better adaptation to a wide range of environmental conditions, low cost of seeds, high oil content, small gestation period and smaller plant size that makes the seed collection easier (Sujatha, 2006).

1.1 **Botany of Jatropha**

The genus *Jatropha* belongs to tribe *Joannesieae* of the Sub-family *Crotonoideae* in the *Euphorbiaceae* family and contains approximately 170 known species (Heller, 1996). According to Dehgan and Webster (1979), synonyms of the physic nut are: *Curcas purgans* L. (Medik); *Curcas curcas* (L.) Britton and Millsp; *Ricinus americanus* Miller; *Castiglionia lobata* (Ruiz and Pavon); *Jatropha edulis* L. (Cerv); *Jatropha acerifolia* L. (Salisb); *Ricinus jarak* (Thunb); *Curcas adansoni* L. (Endl).; *Curcas indica* A. (Rich).; *Jatropha yucatanensis* L. (Briq).

The plant is monoecious and flowers are unisexual (Dehgan and Webster 1979).The female flowers are 4-5 times more numerous than the male ones. Ten stamens are arranged in two distinct whorls of five each in a single column in the androecium and in close proximity to each other. In the gynoecium, the three slender styles are connate to about two-thirds of their length, dilating to massive bifurcate stigmata. Jatropha is pollinated by insects and it is believed to be pollinated by moths because of "its sweet heavy perfume at night, greenish white flowers, versatile anthers and protruding sexual organs, copious nectar, and absence of visible nectar guides" (Heller, 1996). Occasionally, hermaphrodite flowers (which can be self-pollinating) occur with male and female flowers on the same plant and in the same inflorescence (Raju, 2002). A trilocular ellipsoid fruit is formed after pollination. The exocarp remains fleshy until the seeds are mature. Fruit development needs 90 days from flowering until seeds mature. Shrubs begin to produce at 4-5 months and reach full productivity at about 3 years. The inflorescence is a cyme formed terminally on branches and is complex, possessing main and co-florescence with paracladium.

If conditions like soil moisture and temperature are good and sufficiently high, the plant can bear fruits throughout the year. A bunch of at least 10 ovoid fruits can be seen in a single inflorescence. Once the seeds are matured, a three or bi-valved cocci are formed with fleshy outer layer. The fruits do not have the capacity to drop on their own, thus they provide place for manual harvest without any damage or wastage. After 2 to 4 months from the date of fertilization, the capsule changes from green to yellow in color. This indicates that the seeds are matured. The blackish and thin-shelled seeds are lozenge and they appear to be like small castor seeds.

Jatropha has 5 to 7 shallow lobed leaves arranged alternately with a length and width of about 15 and 6 cm respectively. The leaves are large and they appear from green to pale green in color. Normally, five roots are formed from seedlings, one tap and four laterals. However, in vegetatively propagated plants tap roots are not formed (Garg, 2011).

1.2 Economic Importance of Jatropha

Jatropha curcas L. is a drought resistant multipurpose small shrub or small tree with significant economic importance having several potential agricultural, industrial and medicinal uses (Chikpah and Demuyakor, 2013 and Abubakar, 2002). *Jatropha curcas* L. has been found to be the most suitable tree species for the production of biodiesel as it can be grown as a quick yielding plant even in problem soils and adverse climatic conditions (Singh, *et al.,* 2000). The plant has potential to generate rural employment, reclaim wasteland, earn foreign exchange, facilitate the establishment of rural based agro-industries, improve the socio-economy of rural dwellers and lead to overall development of the country (Abubakar, 2010). Seed of Jatropha contains averagely 34.4% oil that can be processed to produce a high quality biodiesel usable in standard diesel engines (Achten, 2008). The oil can be combusted as fuel without being refined. It burns with clear smoke-free flame, tested successfully as fuel for simple diesel engine (CJP, 2012). According to Kabir (2009), cars do not need to be modified to use the resulting biodiesel from Jatropha. Thus, the plant can be used in saving the major portion of Nigeria's valuable foreign exchange reserve, which is spent on meeting the import bill of petroleum products. Seed yields under cultivation can range from 1,500 to 2,000 k/ha corresponding to extractable oil yields of 540 to 680 l/ha (Dar, 2007). The oil has high saponification value (Adebowale and Adediren, 2006) and can be used for illumination, soaps, candles and the making of Turkey red oil also called sulphonated (or sulfated) castor oil; the only oil that completely disperses in water made by adding sulfuric acid to *Jatropha* oil. It is used in formulating lubricants, softeners and as dyeing assistants.

1.3 Cultivation of Jatropha

Jatropha curcas L. is found in tropical and subtropical regions. It grows on well-drained soils with good aeration and is well adapted to marginal soils with low nutrient content (Openshaw, 2000). There are various methods to cultivate *Jatropha*, which vary from region to region and also on climatic conditions. These are: direct seeding, pre-cultivation of seedlings (nursery raising), transplanting of spontaneous wild plants and direct planting of cuttings. Wider spacing (3m x 3m) is reported to give larger yields of fruit, at least in early years (Heller, 1996). Although Jatropha grows readily from seeds or cuttings, trees propagated by cuttings show a lower longevity and possess a lower drought resistance than those propagated by seeds because of the absence of true tap roots which can absorb water from the deep soil (Heller, 1996). For quick establishment of hedges and plantation for erosion control, directly planted cuttings are best. However, for long-lived plantations for vegetative oil production, plants propagated by seeds are better.

According to the topography, soil profile and prevailing agro climatic conditions in an area, Jatropha can be combined with other suitable species comprising the agricultural, horticultural herbs, pastoral and/or silvicultural components to result in an ecologically viable, economically profitable and socially acceptable agro forestry system. The growth and yield of Jatropha could be improved through effective management practices. Standard cultural practices are timely weeding (4 times a year), proper fertilization, surface ploughing and pruning. With these management practices a yield of about 15-20 kg of fruit per tree can be obtained even if the plants did not reach full maturity.

1.4 Justification of the Study

Jatropha is a very important crop in Nigeria having medicinal, environmental and industrial uses especially the potential to yield high quality biodiesel that is environmentally friendly. Scientific evidence for elite accessions and adequate breeding work on the crop in Nigeria are lacking. Thus, the crop is in its infancy with respect to genetic improvement especially for increasing seed and oil yield per unit area. However, breeding of high yielding variety is not possible without knowing the extent of variation that exists among the available germplasm. In order to achieve this, provenance research will be the quickest and simplest step to start. The provenance research will help, as an initiative, to study pattern of diversity for various traits and identify *Jatropha curcas* L. provenances that are well adapted and have high desirable traits. The present work was therefore, undertaken to evaluate twenty one provenances of the *Jatropha curcas* L. with the aim of selection for future breeding program. The provenance trial will also help in defining the genetic and environmental components of phenotypic variation associated with geographic sources. Information on this is important in assuring sources of seed to give well-adapted and productive trees and in directing breeding of interracial and interspecific hybrids toward adaptation to particular localities.

1.5 Objectives of the Study

The objectives of this study were to determine:

i. variation pattern in the *Jatropha curcas* L. provenances
ii. major traits responsible for the variation of the provenances, and
iii. suggest potential provenances that could be used in hybridization programme

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Provenance Research

The term provenance refers to the geographic source of seed or plant material or to the plants from such a source (Burley, 1969). Variation is the occurrence of differences among individuals due to differences in their genetic composition and/or the environment in which they grow (Falconer and Mackay, 1996). It is generally true that tree species, such as Jatropha, with a wide geographical distribution exhibit considerable provenance variation in anatomy, morphology and physiology. According to Wouter *et al.* (2010), prebreeding knowledge in *Jatropha curcas* L. is limited and in particular, the regeneration ecology and the degree of genetic diversity among and within natural populations in and outside the center of origin are poorly studied. Provenance research is the expression used in forestry for the analysis of plantations of tree populations originating from geographically different locations (Matyas, 1997). Provenance research aims at defining the genetic and environmental components of phenotypic variability between trees from different geographic origins (Callaham, 1962). Provenance variation studies are the quickest and simplest methods of obtaining highly adaptive and productive trees in forestry because forest trees seem to be very difficult objects for controlled environment tests due to their size and lifespan. Provenance trials and research into the genetics of *Jatropha curcas* L. has shown that there is some genetic variation between plants or accessions from different provenances that are growing worldwide and plants grown from the same seed source can differ considerably in morphological aspects like plant height and seed production. Eric (2010) added that it is not yet known to what extent this morphological variation can be

attributed to genetic or environmental factors. *Jatropha curcas* L. can be improved through assessment of variation in wild sources and selection of superior/elite genotypes and application of mutation, alien gene transfer through inter-specific hybridization and biotechnological interventions to bring the change in the desired traits (Divakara *et al.*, 2009).

2.2 Origin and Distribution of *Jatropha curcas* L.

Jatropha curcas L. originated from Central America and Mexico from where it spread to other parts of the world. It was probably distributed by Portuguese seafarers through the Cape Verde Islands and present Guinea Bissau to other Asian and African countries (Heller, 1996). It is now found in almost all tropical and subtropical countries as living fence (hedge) because animals do not browse on it (Garg*et al.*, 2011). *Jatropha curcas* has spread beyond its original distribution because of its hardiness, easy propagation, drought endurance, high oil content, low seed cost, short gestation period, rapid growth, adaptation to wide agro-climatic conditions, bushy/shrubby nature and multiple uses of different plant parts (Divakara *et al.*, 2009).

2.3 Variability in *Jatropha curcas* L.

Crop improvement depends largely on the availability of diverse germplasm and their efficient utilization (Tukat *et al.*, 2009). The starting point in any breeding programme is the original variability in the wild population that forms the basis of selection (Bawa, 1976). It is important to classify the range of variability among accessions to facilitate the maintenance and further acquisition of germplasm resources. Thus, the wealth of any germplasm collection is measured in terms of the genetic variability of the crop species it contains (Idehen *et al.*, 2007).The extent of variability is measured by genotypic coefficient

of variation (GCV) and phenotypic coefficient of variation (PCV), which provide information about the relative amount of variation in different characters (Roychowdhury and Tah, 2011). According to Krishnaswami *et al.* (1982), wide margin between PCV and GCV for any character shows that environmental influence operating on that character is appreciably larger than the genetic influence operating on it. The success of any breeding programme is contingent upon information about the amount and pattern of variation and the reproductive biology of the species involved (Aghughu, 2001).

Gohil and Pandya (2009) reported higher phenotypic coefficients of variations for plant height, plant canopy, collar diameter, number of primary and secondary branches, average seed weight, number of seeds and capsules, number of leaves, seed yield and oil content in a study to determine the extent of variability, GCV, PCV, heritability, genetic advance and genetic gain for 14 characters in nine genotypes (including two non-toxic species) of *Jatropha curcas* L. In the evaluation of 16 *Jatropha curcas* genotypes for 12 characters, Das *et al.*,(2010) reported that PCV and GCV estimates were high for seed yield/plant followed by flowering bunches/plant, fruits/plant and secondary branches/plant.

Provenance trials and research into the genetics of *Jatropha curcas* L. has shown that there is some genetic variation between plants from different provenances (or accessions) that are growing worldwide. Natural genetic variation between provenances for *Jatropha* is largest in the center of origin, Central America and the Northern parts of South America (Eric, 2010).

2.4 Heritability Estimates in Jatropha Studies

Heritability analyses estimate the relative contribution of differences in genetic and non-genetic factors to the total phenotypic variance in a population (Anon., 2009). The amount of natural variations in economic characters in forest trees is useful if the variations are under genetic control. In an evaluation of six *Jatropha curcas* L. accessions, Rafii *et al* (2012) reported a broadsense heritability values ranging from 0 to 23.04% with highest value for plant height. This study indicated that environmental factors played an important role than the genetic factor. Gohil and Pandya (2009) reported that plant canopy, seed yield and number of leaves, seed oil and kernel oil content had high heritability coupled with high genetic advance. So these may be considered for selection to improve Jatropha varieties/genotypes. Rao *et al*., (2008) found a high heritability for plant height (0.87) oil content (99%), weight of 100 seeds (93%) and seed width (77%). Similarly, Kaushik *et al*. (2007) found high heritability estimates for seed weight (0.96) and oil content (0.99).

2.5 The Need for Biodiesel as an Alternative Fuel

Biodiesel is an alternative fuel that is prepared from vegetable oil, animal oil, fats and also from waste cooking oil (Anon., 2009). Biodiesel is a liquid fuel, technically known as a monoalkyl ester, made from fats or oils and alcohols. During the early 20^{th} century, Diesel (1912) pointed out that the use of vegetable oils as engine fuels may seem insignificant at that time but the use of such oils may become, in the course of time, as important as petroleum and the coal tar products of the time. However, at present there is rekindled interest in biofuel and biomass energy (Anon., 2002). In view of growing interest for renewable energy sources, liquid bio-energy production from vegetable oils is one of the

possible options to reduce greenhouse gas (GHG) emissions (Divakara *et al.*, 2009). Energy crops such as Jatropha, sweet sorghum, fast growing trees, and grasses are known as bio-crop and biomass feedstock. Among the many species, which yield oil as a source of energy in the form of biodiesel, *Jatropha curcas* L. has been identified as most suitable oil seed bearing plant due to its various favorable attributes like hardy nature, short gestation period, adaptability in a wide range agro-climatic conditions, high oil recovery and quality of oil, etc. According to Divakara *et al.* (2009), biomass as a source of renewable energy is fundamental for development and sustenance of civilization. It has been increasingly apparent that the production of biofuels must originate from non-food crops dedicated solely to energy production. Although Jatropha cannot solve all problems related to energy in developing countries, it is likely to be one of the most promising biofuel crops that would also contribute to sustainable agriculture and improved livelihoods (Cramer, 2010).

2.6 Correlations between Morphological Traits and Oil Content in Jatropha

Correlation coefficient between any pair of characters is a measure of the mutual association between them (Snedecor and Cochran, 1967). The information on nature and magnitude of associations helps breeders to determine the selection criteria for simultaneous improvement of various characters along with seed yield (Thanki and Sawargaonkar, 2010). The association can be positive when the two characters tend to rise or fall together or negative when rise or fall in one of the characters leads to a change in the other character in the opposite direction. The importance of correlation studies in selection programmes is appreciable when highly heritable characters are associated with an

important character like yield (Manggoel *et al.*, 2012). The values of the correlation coefficient range from -1 to +1.

In the genetic diversity assessment of 59 accessions of *Jatropha curcas,* Mahmoodreza *et al.* (2011) found highly positive correlations between fruit length and fruit width, fruit length and seed length, fruit width and seed length, fruit length and seed width, fruit width and seed width and seed length and seed width. In the correlation study of six *Jatropha curcas* L. accessions, Rafii *et al.* (2012) found that seed length had positive correlation with seed thickness, seed breadth and seed weight.

The existence of juvenile-mature correlation in characters slated for improvement will enable the breeder carry out early selection, thus reducing the time required for the improvement programme (Aghughu, 2001). According to Callaham (1962), 50 to 80 years of testing might be required to identify the best seed sources of fast-growing tree crop species. Hence, he pointed out that information on correlation between juvenile and matured plant characters is desired in tree crops studies.

2.7 Principal Component Analysis

Principal Component Analysis (PCA) has been widely used in the studies of variability in germplasm collections of many species (Zakova and Benkova, 2006; Tukat *et al*., 2009). PCA is a very useful multivariate method because it reveals the relationships and correlation among variables studied. The PCA gives a better understanding of the structure of reference collection, identification of more relevant variables, detection of the

relationships among accession, as well as identification of possible groups (Martinez-Calvo *et al*., 2008). PCA and correlation coefficients analysis in germplasm collections facilitate reliable classification of genotypes, identification of subsets of core genotypes and correlated morphological characters with possible utility for specific breeding purposes. Cartea *et al*. (2002) used PCA and cluster analysis to group kale populations and winter wheat genotypes. Žáková and Benková (2006) used PCA to identify the main traits that were responsible for the variation or genetic diversity among 106 Slovakian barley accessions. The PCA reduces the dimension of a multivariate data into few principal axes, generates an eigenvector for each axis and produces component scores for each character (Sneath and Sokal, 1973). The relative discriminating power of axes and their associated characters are measured by eigenvalues and factor scores, respectively (Idehen *et al*., 2007). This method which is a common ordination technique reduces the dimension of multivariate data by removing inter-correlations among attribute-variables (characters on which units are to be compared), and enables multidimensional relationships to be plotted on two or three principal axes (Hayman, 1967).

Kaiser (1960) stated that as a criterion, the number of common factors to be retained should be equal to the number of principal components having eigenvalues greater than one. The rationale for this consideration is easy to understand. Each of the ten traits observed contributes one unit of variance to the total variance in the data set. This implies that any component that displays an eigenvalue greater than 1.00 is accounting for a greater amount of variance than had been contributed by one variable. Thus, such a component is considered accounting for a meaningful amount of variance, and therefore deserves to be retained. On the other hand, a component with an eigenvalue less than 1.00 is accounting

for less variance than had been contributed by one variable. The purpose of principal component analysis is to reduce the number of observed variables into a relatively smaller number of components; this cannot be effectively achieved if you retain components that account for less variance than had been contributed by individual variables. For this reason, components with eigenvalues less than 1.00 are viewed as trivial and are therefore not retained. Eigenvalues can be thought of as quantitative assessment of how much a component represents the data. The higher the eigenvalues of a component, the more representative it is of the data.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Germplasm Collection Expeditions and Available Accessions

A survey and collection of *Jatropha curcas* L. germplasm from the Northwestern zone of Nigeria was conducted in the year 2009. Thirty three (33) accessions were collected from the seven states of the zone which spans across the Sahel, Sudan and Guinea Savannas and formed the genetic materials for this research. The states were Sokoto, Kebbi, Zamfara, Katsina, Kaduna, Kano and Jigawa. The Eco-geographical characteristic of the survey area is presented in Table 3.1. A provenance trial was established from these collections at Samaru (11º11'N, 07º38'E) in 2009. All agronomic activities such as ploughing and harrowing were carried out on the field before establishing the trials.

3.2 Experimental Materials and Field Layout

The experimental materials were the three year old *Jatropha curcas* accessions planted in the Institute for Agricultural Research Farm Samaru in 2009. Each accession, a representative of a provenance, contained 20 ± 2 trees planted in single row plots of 44m long with 3m inter- and intra-row spacing. Each stand was considered as a replication. A total of 33 accessions were planted out of which 3 from each state were selected making a total of 21 provenances for this research. The field was harrowed, ploughed and ridged in December before establishing the provenances in the field.

Table 3.1:Eco geographical characteristics of the survey area in the Northwestern Zone of Nigeria where Jatropha curcas L. germplasm were collected

State	Latitude (N)	Longitude (E)	Zone	Soil type	Climate
Kaduna	$9^{o}11'$-$11^{O}22'$	$8^{0}21'$-$7^{0}14'$	NGS, SGS	Alfisols	Tropical wet and dry
Katsina	$11^{0}23'$-$13^{0}07'$	$7^{o}23'$-$7^{o}47'$	SSS	Entisols	Tropical wet and dry
Kano	$11^{o}06'$-$11^{o}58'$	9^{o}-00'-$9^{o}02'$	SS	Alfisols	Hot and semi-arid
Jigawa	$11^{o}00'$-$11^{o}33'$	$9^{o}30'$-$9^{o}34'$	SSS	Alfisols	Hot and semi-arid
Zamfara	$11^{o}56'$-$13^{0}07'$	$6^{o}25'$-$6^{o}43'$	SSS	Entisols	Hot and semi-arid
Sokoto	$12^{o}03'$-$13^{o}10'$	$5^{o}46'$-$4^{o}33'$	SSS, NGS	Entisols	Hot and semi-arid
Kebbi	$12^{o}05'$-$12^{0}41'$	$4^{o}07'$-$4^{o}26'$	SSS	Entisols	Hot and semi-arid

SS: Sudan Savannah, NGS: Northern Guinea Savannah, SSS: Sudano-Sahelian Savannah:
Source: Halilu *et al.* (2011)

Table 3. 2: List of Provenances, their Accession Numbers and Collection States

S/no	Provenance	Accession	State
1	Kangire	IARJAT2009027	Jigawa
2	Masaya	IARJAT2009007	Jigawa
3	Burum	IARJAT2009003	Jigawa
4	Kakiyayi	IARJAT2009016	Kaduna
5	Soba	IARJAT2009001	Kaduna
6	Bakingada	IARJAT2009031	Kaduna
7	Dirbindai	IARJAT2009035	Kano
8	Ruwankanya	IARJAT2009036	Kano
9	Gwarzo	IARJAT2009039	Kano
10	Danjanku	IARJAT2009024	Katsina
11	Karofi	IARJAT2009043	Katsina
12	Dankama	IARJAT2009011	Katsina
13	Sabongarin Dabai	IARJAT2009017	Kebbi
14	Jega Birni	IARJAT2009010	Kebbi
15	Maga	IARJAT2009008	Kebbi
16	Tsaki	IARJAT2009013	Sokoto
17	Kajiji	IARJAT2009014	Sokoto
18	Famfo	IARJAT2009015	Sokoto
19	Kwanan Maje	IARJAT2009022	Zamfara
20	Daki Takwas	IARJAT2009023	Zamfara
21	Take Tsaba	IARJAT2009021	Zamfara

SS: Sudan Savannah, NGS: Northern Guinea Savannah, SSS: Sudano-Sahelian Savannah:

3.3 Data Collection

Data were taken on ten selected trees from each provenance each provenance taken as replication. The morphological traits of the plants and seeds assessed were specifically:

3.3.1 Plant height (cm):

This was taken as the height from the ground level to the tip of plant using graduated meter rule. The measurement was taken to the nearest whole number.

3.3.2 Seed oil content:

This was done by the extraction of fat content from the seeds using petroleum ether in a soxhlet extractor as described by Shivani *et al*. (2011)

3.3.3 Main stem height (cm):

This was taken as the height of the main axis of the plant from the ground level measured using graduated meter rule.

3.3.4 Collar height (cm):

This was taken as the height from the ground level to where the first branch appeared using measuring tape.

3.3.5 Collar thickness (cm):

This was taken as the thickness of the stem from the ground level to the collar of the plant using measuring tape.

3.3.6 Number of branches on collar:

This was counted as the number of branches that shoots out at the collar of the plant.

3.3.7 Number of lateral branches:

This was counted as the total number of lateral branches on the main axis of the plant.

3.3.8 Number of fruit bunch per lateral branch:

This was counted as the total number of bunches of fruit on a plant divided by the number lateral branches.

3.3.9 Number of capsule per bunch:

This was the number of capsules divided by the number of bunches.

3.3.10 Number of capsule per lateral branch:

This was the total number of capsules divided by the number of lateral branches.

3.4 Statistical Analysis

Analysis of variance was carried out using the generalized linear model (GLM) in SAS (SAS Institute Inc.2004). The experimental design was Randomized Complete Block Design.

The model used for the analysis was:

$$Y_{ijkl} = \mu + \gamma_k + \varepsilon_{ijkl}$$

Where;

Y_{ijkl} = tree$_{\mathbf{l}}$ in treatment combination$_{\mathbf{ijk}}$

μ = the grand mean,

γ_k = provenance$_{\mathbf{k}}$,

ε_{ijkl} = Residual error.

Table 3. 3: Form of Analysis of Variance for Nine Morphological Traits and Oil Content in *Jatropha curcas* L.

Sources of Variation	DF	MS	EMS
Replication	$(r-1)$	MS_r	
Provenance	$(p-1)$	MS_p	$\sigma_e^2 + r\sigma_p^2$
Error	$(p-1)(r-1)$	MS_e	σ_e^2

Mean separation was done by Least Significant Difference (LSD). Coefficient of variation was computed and then used to compare variability of each character studied. Genetic distances were estimated using Mean Euclidean Distance as suggested by Kaushik (2007):

$$d_{ij} = \sqrt{\frac{1}{k}\sum_{1}^{k}(X_{ik} - X_{jk})^2}$$

Where d_{ij}= genetic distance between two genotypes

K =number of genotypes

X_{ik}= genotype 1

X_{jk}= genotype 2

3.5 Rank Summation Index

For the purpose of selection, an index, Rank Summation Index (RSI) according to Malumba and Mock (1978) was generated from five traits namely plant height, number of fruit bunch per lateral branch, number of lateral branches, number of capsules per bunch and oil content. Malumba and Mock (1978) described the rank summation index and called it "parameter- free" index. The index was formed by ranking each trait in descending order. Finally, the values assigned to each trait are added, obtaining the sum of the ranks, which

indicates the classification of the provenances (Cruz and Ragazzi, 2001). Entry with good plant height, number of lateral branches and yield of seeds ranked first, while the reverse ranked last. Rank Summation Index as computed by Malumba and Mock (1978) was summarized as follows;

$$RSI = \sum_{i=1}^{n} R_i s$$

Where,

RSI = Aggregate performance of a provenance using the ranking of each of the desired traits

R_i= Rank of the mean of each of the desired traits

3.6 Estimation of Components of Variance

The contribution of each component of variance to the total phenotypic variation was calculated by equating the appropriate mean squares to the expectation of mean squares (EMS) from the ANOVA Table using the method described by Singh and Chaudhary (1985) as follows:

$$\sigma_e^2 = M_e$$

$$\sigma_g^2 = \frac{M_2 - M_1}{r}$$

Where,

σ_e^2 = Error variance M_1 = Error mean square

M_2 = Genotypic mean square r = Number of replications

σ_g^2 = Genotypic variance

3.7 Correlations

Phenotypic and genotypic correlation coefficients were estimated for all possible pairs of characters examined. Phenotypic and genotypic correlations were estimated using the standard procedure suggested by Miller *et al.* (1958) and used by Kashiani and Saleh (2010) from the corresponding variance and covariance components using the equations:

$$r_{pxy} = \frac{\sigma_{pxy}}{\sqrt{\sigma^2_{px} * \sigma^2_{py}}} \quad \text{and} \quad r_{gxy} = \frac{\sigma_{gxy}}{\sqrt{\sigma^2_{gx} * \sigma^2_{gy}}}$$

Where,

r_{pxy} = Phenotypic correlation coefficient between characters X and Y

σ^2_{px} = Phenotypic variance of character x

σ^2_{py} = Phenotypic variance of character y

r_{gxy} = Genotypic correlation coefficient between characters X and Y

σ^2_{gx} = Genotypic variance of character x

σ^2_{gy} = Genotypic variance of character Y

3.8 Heritability

Broadsense heritability was estimated after Eckebil *et al.* (1977) as follows:

$$h^2_b = \frac{\sigma^2_g}{\sigma^2_{ph}}$$ Where

h^2_b = Broadsense heritability, σ^2_g = Genotypic variance, σ^2_{ph} = Phenotypic variance

3.9 Principal Component Analysis

The technique of principal component analysis was employed in order to analyze the variability in the provenances, determine the plant traits which cause the variation to arise and to determine the relative contributions that the various traits make to the total variability in the provenances. With 10 traits and 21 *Jatropha curcas* L. provenances, a data matrix of 10 × 21 was prepared for the analysis. In principal component analysis, one of the most commonly used criteria for solving the number-of-components problem is the eigenvalue-one criterion, also known as the Kaiser criterion (Kaiser, 1960). With this approach, you retain and interpret any component with an eigenvalue greater than 1.00. Thus, principal components with eigenvalue 1 were used for further analyses. Important traits in each principal component were determined from the associated eigen vectors.

CHAPTER FOUR

4.0 RESULTS

4.1Analysis of Variance

The Mean squares from Analysis of Variance for the nine morphological traits and oil content studied are shown in Table 4.1. Highly significant differences ($P \leq 0.01$) were obtained for provenances in all traits except main stem height which was significant at $P \leq 0.05$. Estimates of components of variances and broadsense heritability were obtained for all the traits from the analysis of variance (Table 4.2). All the morphological traits had higher error variances (σ^2_e) than their genotypic variances (σ^2_g) except for plant height, number of branches on collar, number of lateral branches, number of capsules per lateral branch and oil content. The heritability values ranged from 15.15% for collar thickness to 91.70%foroil content.

4.2 Mean Performance

The mean performance for the nine morphological traits and oil content studied is presented in Table 4.3. The mean for plant height is 191.94cm and ranged from provenance with lowest plant height Tsaki, 165.70cm to the provenance with highest plant height Kwanan Maje, 220.00cm. Three provenances Kangire, Soba and Kwanan Maje have mean performance of 4.72%, 10.08% and 14.62% over the mean of all provenances for plant height. However, the mean for main stem height is 173.03cm and ranged from provenance with lowest main stem height Tsaki, 151.20cm to the provenance with highest main stem height Soba, 191.30cm. The collar height ranged from 6.8cm for Gwarzo, Ruwan Kanya and Maga to13.60cm for Soba. The collar thickness ranged from 49.20cm for Burum to

95.5cm for Karofi. Number of branches on collar ranged from 1.90 to 5.4 for Burum and Daki Takwas respectively. The number of lateral branches on the other hand ranged from provenance with lowest number of lateral branches Daki Takwas, 1.90 to the provenance with highest number of lateral branches Tsaki, 6.70. Number of fruit bunch per lateral branch ranged from 1.30 to 3.40. The highest and lowest yielding provenances were Karofi and Daki Takwas respectively. Number of capsules per bunch has a mean of 3.4 and ranged from 1.50 to 4.8 for Daki Takwas and Burum. Number of capsules per lateral branch has a mean of 4.9 and ranged from 1.40 for Kwanan Maje to 7.9 for Tsaki. Oil content however, ranged from 39.3% for Famfo to 44.4% for Dirbindai.

The coefficients of range and coefficients of variation for all the morphological traits and oil content studied are also presented in Table 4.3. High coefficient of range in the means were recorded for number of capsules per lateral branch (0.70), number of lateral branches (0.56) and number of capsules per bunch (0.52). The coefficient of variation ranged from 1.0 percent for oil content to 26.1 percent for number of fruit bunch per lateral branch. The traits which showed high level of variations were the number of fruit bunch per lateral branch, number of capsules per bunch, number of branches on collar and number of capsules per lateral branch.

Table 4. 1: Mean Squares from the Analysis of Variance for Nine Morphological Traits and Oil Content in 21 *Jatropha curcas* L. Provenances

Source	DF	PH	MSH	CH	CT	BOC	LB	FBPL	CPB	CPL	OC (%)
Replication	9	261.85	314.98	1.77	109.77	0.35	0.61	0.16	0.98	3.03	0.12
Provenance	20	1617.48**	1102.49*	29.06**	158.84**	7.95**	8.92**	2.92**	6.91**	30.97**	19.0**
Error	180	131.54	148.07	3.29	57.01	0.50	0.69	0.43	0.70	1.31	0.17
Total	209										

Key:
PH=Plant height (cm), MSH=Main stem height(cm), CH= Collar height(cm), CT = Collar thickness (cm), BOC = Number of branches on collar, LB=Number of lateral branches, FBPL= Number of fruit bunch per lateral branch, CPB=Number of capsules per bunch, CPL=Number of capsules per lateral branch, OC=Oil content, CR: Coefficient of Range = L-S/L+S, Where: L = Highest value, S = Lowest value, CV%: Coefficient of Variation (%) =SD/Mean *** =** Significant at 0.05 level of probability, ****** = Significant at 0.01 level of probability

Table 4. 2: Estimates of Error, Genotypic and Phenotypic Variances and Broadsense Heritability for Morphological Traits and Oil Content in *Jatropha curcas* L. Provenances

Traits	Means	σ_e^2	σ_g^2	σ_{ph}^2	h_b^2 (%)
Plant Height	191.9	131.54	148.60	280.14	53.05
Main Stem Height	173.0	148.07	95.44	243.51	39.19
Collar Height	9.0	3.29	2.58	5.87	43.95
Collar Thickness	57.2	57.01	10.18	67.19	15.15
Number of Branches on Collar	2.9	0.50	0.75	1.25	60.00
Number of Lateral Branches	5.4	0.69	0.82	1.51	54.30
Number of Fruit Bunch per Lateral Branch	2.5	0.43	0.25	0.68	36.77
Number of Capsules per Bunch	3.4	0.70	0.62	1.32	46.97
Number of Capsules per Lateral Branch	4.9	1.31	2.97	4.28	69.39
Oil Content	42.0	0.17	1.88	2.05	91.70

Table 4. 3: Mean Performance for the Morphological Traits of 21 *Jatropha curcas* L. Provenances

Provenances	PH	MSH	CH	CT	BOC	LB	FBPL	CPB	CPL	OC
Kwanan Maje	220.0	183.1	13.6	53.3	2.0	4.7	1.6	1.8	1.4	42.3
Soba	211.3	191.3	10.6	57.7	3.8	6.4	3.0	3.8	5.0	43.0
Kangire	201.0	173.5	9.3	53.8	2.1	4.8	1.8	2.3	3.0	42.2
Danjanku	199.1	177.8	9.6	54.5	3.8	6.4	2.5	3.8	5.3	40.9
Dankama	199.0	179.4	8.8	61	2.3	5.9	2.5	4.0	5.9	40.9
Gwarzo	198.9	180.7	6.8	63.0	3.6	5.4	3.1	4.3	7.4	44.0
Daki Takwas	198.6	178.5	8.5	66.0	5.4	1.9	1.3	1.5	1.8	42.5
Sabongarin Dabai	198.0	184.1	9.7	57.5	2.0	5.6	2.5	3.3	4.1	42.4
Jega Birni	195.6	180.3	9.4	57.7	2.3	5.5	2.6	3.1	5.5	40.6
Ruwan Kanya	194.4	183.6	6.8	63.0	3.6	5.4	3.1	4.3	7.4	43.9
Take Tsaba	192.0	174.5	11.8	54.1	2.0	5.3	2.0	3.9	2.2	42.5
Burum	191.0	172.6	11.4	49.2	1.9	5.6	3.3	4.8	6.8	41.1
Bakingada	190.8	174.3	9.3	54.5	3.8	6.4	2.5	3.8	4.7	42.6
Kakiyayi	190.2	168.7	10.7	55.0	2.5	5.8	2.5	3.4	5.7	43.9
Famfo	189.1	172.5	10.7	55.0	2.5	5.8	2.3	3.5	5.3	39.3
Masaya	186.5	169.4	7.5	58.6	3.3	5.1	2.2	2.9	5.1	40.9
Maga	183.5	164.7	6.8	56.7	3.4	5.0	3.0	3.0	4.8	42.7
Karofi	180.5	160.2	8.9	95.5	3.3	5.3	3.4	3.2	4.1	40.7
Dirbindai	178.9	161.5	9.1	58.1	2.7	5.2	2.3	3.4	5.0	44.4
Kajiji	166.7	151.8	8.5	61.9	2.5	5.0	2.5	3.3	4.3	40.8
Tsaki	165.7	151.2	9.4	54.9	2.3	6.7	2.4	4.5	7.9	40.9
Mean	191.9	173.0	9.0	57.2	2.9	5.4	2.5	3.4	4.9	42.0
Coefficient of Range	0.14	0.12	0.33	0.32	0.48	0.56	0.45	0.52	0.70	0.06
C.V%	6.0	7.0	19.3	13.2	24.2	15.5	26.1	24.5	23.4	1.0
LSD	10.12	10.74	1.60	6.66	0.62	0.74	0.58	0.74	1.01	0.36

PH=Plant height, MSH=Main stem height, CH=Collar height, CT=Collar thickness, BOC=Number of branches on collar, LB=Number of lateral branches, FBPL=Number of fruit bunch per lateral branch, CPB=Number of capsules per bunch, CPL=Number of capsules per lateral branch, OC=Oil content, CR: Coefficient of Range = L-S/L+S, Where: L = Highest value, S = Lowest value, CV%: Coefficient of Variation (%) =SD/Mean

4.3 Rank Summation Index

The rank summation indices on five selected traits, plant height, number of lateral branches, number of fruit bunch per lateral branch, number capsules per bunch and oil content as computed according to Malumba and Mock (1978), is presented in Table 4.4. Soba, Gwarzo and Ruwan kanya ranked first, second and third with rank summation indices of 20, 21 and 27 respectively while Masaya ranked last with rank summation index of 72.

4.4 Genetic distance

Pairwise genetic distance estimates for the 21 *Jatropha curcas* L. provenances ranged from 1.56 for Dankama and Gwarzo provenances to a maximum of 11.99 for both Kajiji and Tsaki with 16 provenances (Bakingada, Kakiyayi, Soba, Gwarzo, Ruwan kanya, Dirbindai, Masaya, Kangire, Burum, Jega Birni, Sabongarin Dabai, Maga, Kwanan Maje, Take Tsaba, Daki Takwas and Famfo) (Table 4.5). Highest genetic distance estimates of 11.99 were also observed between both Kajiji and Tsaki with three provenances (Dankama, Danjanku and Karofi).

Genetic distance estimates for provenance within states ranged from 2.08 (Bakingada and Kakiyayi) to 9.15 (Soba and Bakingada, Soba and Kakiyayi) within Kaduna state with a mean genetic distance of 6.79. Within Jigawa state, the genetic distance estimates ranged from 3.94 for Kangire and Burum to 6.25 (each for Masaya and Kangire and Masaya and Burum) with a mean of 5.48. The mean genetic distance within Kano state on the other hand is 4.86 ranging from 2.08 (Gwarzo and Ruwankanya) to 6.25 (each for Dirbindai and Gwarzo and Dirbindai and Ruwan kanya). However, provenances within Katsina state have a mean genetic distance of 5.03 with minimum genetic distance of 2.59 (Danjanku and Dankama) and maximum genetic distance of 6.25 for Karofi and Danjanku as well as

Karofi and Dankama. Sokoto state provenances have a mean genetic distance of 8.86 and a minimum genetic distance of 2.59 between Kajiji and Tsaki and a maximum genetic distance of 11.99 (Famfo and Kajiji, Famfo and Tsaki). Looking at provenances within Kebbi state, the mean genetic distance is 4.70. The maximum genetic distance is 6.25 for Maga and Jega Birni and similarly Maga and Sabongarin Dabai while the minimum genetic distance is 1.60 for Jega Birni and Sabongarin Dabai provenances. Finally, the genetic distance estimate for provenances from Zamfara state ranged from 4.46 for Take Tsaba and Daki Takwas to 9.15 for Kwanan Maje and Take Tsaba and for Kwanan Maje and Daki Takwas provenances with a mean genetic distance of 7.59.

Table 4. 4: Rank Summation Indices on five Morphological Traits and Oil Content in 21 *Jatropha curcas* L. Provenances

Provenance	PH	FBPL	LB	CPB	OC	RNK
Soba	2	5	2	6	5	20
Gwarzo	6	3	7	3	2	21
Ruwan Kanya	10	4	7	3	3	27
Burum	12	2	5	1	13	33
Danjanku	4	8	2	6	14	34
Dankama	5	9	3	4	15	36
Bakingada	13	11	2	6	7	39
Kakiyayi	14	12	4	8	4	42
Sabongarin Dabai	8	10	5	9	10	42
Take Tsaba	11	18	8	5	9	51
Maga	17	6	11	12	6	52
Dirbindai	19	16	9	8	1	53
Jega Birni	9	7	6	11	20	53
Tsaki	21	14	1	2	17	55
Karofi	18	1	8	10	19	56
Kwanan Maje	1	20	13	15	11	60
Kangire	3	19	12	14	12	60
Famfo	15	15	4	7	21	62
Daki Takwas	7	21	14	16	8	66
Kajiji	20	13	11	9	18	71
Masaya	16	17	10	13	16	72

PH---Plant height (cm), FBPL---Number of fruit bunch per lateral branch, LB---Number of lateral branches, CPB---Number capsules per bunch, OC----Oil content, RNK---Rank Summation Index

Table 4. 5: Pair wise Genetic Distance Coefficients for 21 *Jatropha curcas* L. Provenances

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Bakingada																				
Kakiyayi	2.08																			
Soba	9.15	9.15																		
Gwarzo	4.46	4.46	9.15																	
Ruwan Kanya	4.46	4.46	9.15	2.08																
Dirbindai	6.25	6.25	9.15	6.25	6.25															
Masaya	6.25	6.25	9.15	6.25	6.25	2.86														
Kangire	3.94	3.94	9.15	4.46	4.46	6.25	6.25													
Burum	2.29	2.29	9.15	4.46	4.46	6.25	6.25	3.94												
Jega Birni	4.46	4.46	9.15	2.59	2.59	6.25	6.25	4.46	4.46											
Sabongarin Dabai	4.46	4.46	9.15	2.59	2.59	6.25	6.25	4.46	4.46	1.6										
Maga	6.25	6.25	9.15	6.25	6.25	2.86	1.97	6.25	6.25	6.25	6.25									
Kwanan Maje	9.15	9.15	4.44	9.15	9.15	9.15	9.15	9.15	9.15	9.15	9.15	9.15								
Take Tsaba	1.37	2.08	9.15	4.46	4.46	6.25	6.25	3.94	2.29	4.46	4.46	6.25	9.15							
Daki Takwas	4.46	4.46	9.15	3.42	3.42	6.25	6.25	4.46	4.46	3.42	3.42	6.25	9.15	4.46						
Famfo	1.68	2.08	9.15	4.46	4.46	6.25	6.25	3.94	2.29	4.46	4.46	6.25	9.15	1.68	4.46					
Kajiji	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99				
Tsaki	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	11.99	2.59			
Danjanku	4.46	4.46	9.15	2.59	2.59	6.25	6.25	4.46	4.46	2.1	2.1	6.25	9.15	4.46	3.42	4.46	11.99	11.99		
Dankama	4.46	4.46	9.15	1.56	2.08	6.25	6.25	4.46	4.46	2.59	2.59	6.25	9.15	4.46	3.42	4.46	11.99	11.99	2.59	
Karofi	6.25	6.25	9.15	6.25	6.25	1.66	2.86	6.25	6.25	6.25	6.25	2.86	9.15	6.25	6.25	6.25	11.99	11.99	6.25	6.25

4.5 Heritability and Correlation Coefficients

Broadsense heritability estimates were computed for all characters as they had positive σ^2_g using the components of variance estimates (Table 4.2). The heritability values ranged from 15.15% for collar thickness to 91.70% for oil content. Phenotypic and genotypic correlation coefficients were computed for the nine morphological traits and oil content (Table 4.6). Plant height has significant phenotypic correlation with number of fruit bunch per lateral branch and number of capsules per lateral branch (r = 0.2952 and 0.2596respectively) as well as highly significant phenotypic correlation with main stem height (r = 0.8448). Main stem height has significant genotypic and phenotypic correlation with number of fruit bunch per lateral branch (r = 0.2675 and r = 0.3215 respectively). Similarly, significant genotypic correlation was observed between main stem height and number of capsules per bunch (r = 0.2615). Significant phenotypic correlations were found between number of fruit bunch per lateral branch and number of capsules per bunch as well as with number of capsules per lateral branch (r = 0.2655 and 0.3828respectively). A significant phenotypic correlation was also found between number of capsules per bunch and number of capsules per lateral branch (r = 0.3213) and oil content (r = 0.2407). The number of lateral branches has a significant phenotypic correlation with number of branches on collar (r = 0.3861). Number of capsules per lateral branch has significant genotypic correlation with the number of branches on collar (r = 0.2615). A highly significant genotypic correlation was found between oil content and number of capsules per bunch (r = 0.9053).

Highly negative phenotypic correlation was found between collar height and collar thickness (r = -0.6715) and between collar height and number of capsules per lateral branch (r = -0.2631).

4.6 Principal Component Analysis

From the ten principal components extracted, eigenvalues and variances associated with each principal component decreased gradually and stopped at 0.03024 and 0.30% respectively (Table 4.7). Three out of the ten principal components extracted had eigenvalue greater than one and altogether explained 77.07% of the total variability and were thus considered for further analyses. Principal component 1 exhibited 34.77%, Principal components 2 and 3 showed 24.48% and 17.83% variabilities respectively among the provenances for the traits under study. The importance of each trait in each of the first three principal components extracted is shown by the respective eigenvectors (Table 4.8). Results obtained from the study showed that number of fruit bunch per lateral branch, number of capsules per bunch and number of capsules per lateral branch had the highest loadings in principal component 1 (0.433034, 0.481361 and 0.468773 respectively) indicating their significance for this component. On principal component 2, collar thickness, collar height and number of branches on collar were the most important (0.552975, 0.530871 and 0.479458 respectively). The third principal component however was more related to plant height and main stem height with 0.561951 and 0.675272 loadings respectively. Results from Table 4.9 indicated that Gwarzo and Tsaki have the highest loadings on PC1 (2.8468 and 2.4699 respectively). On PC2, Kwanan Maje and Burum have the highest loadings (2.7583 and 2.2407 respectively) while on PC3 Soba and Gwarzo were having the highest loadings (2.7931 and 1.8250 respectively). Summary of

the relationships among the provenances at various levels of similarity are presented in a dendrogram (Figure 1) and the provenances were sorted into four distinct groups (clusters) based on morphological traits and oil content (Table 4.10).

Table 4. 6: Genotypic and Phenotypic Correlations Coefficients between Morphological Traits and Oil Content in *Jatropha curcas* L. Provenances

		MSH	CH	CT	BOC	LB	FBPL	CPB	CPL	OC
PH	G	-0.1458	0.0469	0.0811	0.1900	0.0461	-0.1323	0.0785	0.0777	0.0521
	P	0.8448**	0.1743	0.1465	0.0373	-0.1520	0.2952*	0.2163	0.2596*	-0.0368
MSH	G		0.0095	-0.2086	0.0278	-0.0967	0.2675*	0.2615*	-0.0617	0.2118
	P		0.0041	0.2104	0.1140	-0.0959	0.3214*	0.2205	0.4684**	-0.0543
CH	G			0.2397	0.0031	0.1016	0.1340	-0.1053	-0.0023	-0.2141
	P			-0.6715**	-0.2413	-0.6778**	-0.1570	-0.2006	-0.2631*	0.2375
CT	G				0.0884	0.1481	0.1745	-0.2333	-0.0265	-0.2118
	P				0.3192*	0.4563**	0.0911	0.0748	0.1554	0.0452
BOC	G					0.0753	-0.1625	0.0702	0.2615*	0.0307
	P					0.3861*	-0.0139	-0.3445*	-0.3964*	0.0513
LB	G						0.0274	-0.1176	0.0266	-0.1482
	P						0.2267	0.2510*	0.3740*	0.2933*
FBPL	G							-0.0861	-0.0719	-0.0849
	P							0.2655*	0.3828*	0.1570
CPB	G								0.1411	0.9053**
	P								0.3213*	0.2407
CPL	G									0.1450
	P									0.3340*

PH----------Plant height (cm)
MSH-------Main stem height (cm)
CH---------Collar height (cm)
CT---------Collar thickness (cm)
BOC--------Number of branches on collar
LB---------Number of lateral branches
FBPL-----Number of fruit bunch per lateral branch
CPB------Number of capsules per bunch
CPL------Number of capsules per lateral branch
OC-------Oil Content (%)
P……..Phenotypic correlation
G……..Genotypic correlation
*……Significant at 0.05 Level
**……..Significant at 0.01 Level

Table 4. 7: Eigenvalues of the Correlation Matrix and the Proportion and Total Variance Explained by the principal Components

Principal Components	Eigen value	Difference	Proportion	Cumulative
Prin1	3.4767	1.0291	0.3477	0.3477
Prin2	2.4476	0.6646	0.2448	0.5924
Prin3	1.7830	0.8096	0.1783	0.7707
Prin4	0.9734	0.4964	0.0973	0.8681
Prin5	0.4770	0.1429	0.0477	0.9158
Prin6	0.3341	0.1015	0.0334	0.9492
Prin7	0.2326	0.0767	0.0233	0.9724
Prin8	0.1559	0.0664	0.0156	0.9880
Prin9	0.0895	0.0592	0.0089	0.9970
Prin10	0.0302	_	0.0030	1.0000

Table 4.8: Eigenvectors of Principal Components for 10 Characters in 21 *Jatropha curcas* L. Provenances

Trait	Prin1	Prin2	Prin3
Plant Height	-.295417	0.198753	0.561951
Main Stem Height	-.188415	0.094050	0.675272
Collar Height	-.167114	0.530871	0.006323
Collar Thickness	-.091000	0.552975	0.140050
No. of Branches on Collar	-.112252	0.479458	0.238675
No. of Lateral Branches	0.394445	0.304822	0.167499
No. of Fruit Bunch per Lateral	0.433034	-.050372	0.213671
No. of Capsules Per Bunch	0.481361	0.083240	0.162208
No. of Capsules Per Lateral	0.468773	-.110308	0.135812
Oil Content	-.184008	0.140058	-.182018

Table 4.9: Principal Component Scores for 10 Traits on 21 *Jatropha curcas* L. Provenance

Provenances	PC1	PC2	PC3
Bakingada	0.6048	0.2082	0.4568
Kakiyayi	0.5158	0.9201	-0.3650
Soba	0.1026	0.5769	2.7931
Gwarzo	2.8468	-1.9537	1.8250
Ruwan Kanya	1.4996	-1.9983	1.8131
Dirbindai	0.3702	-0.4873	-1.4112
Masaya	-0.2560	-1.2726	-0.5353
Kangire	-2.7798	1.5179	-1.4407
Burum	1.2331	2.2407	0.2037
Jega Birni	0.0076	0.3077	0.5751
Sabongarin Dabai	-0.4023	0.8139	0.7450
Maga	0.5708	-1.4451	-0.7214
Kwanan Maje	-3.8661	2.7583	0.5034
Take Tsaba	-0.9035	1.8890	-0.5298
Daki Takwas	-5.0110	-3.6329	-0.0424
Famfo	0.2736	0.9836	-0.2505
Kajiji	0.6643	-1.4261	-2.5193
Tsaki	2.4699	0.2030	-2.2130
Danjanku	0.4830	0.4226	1.0994
Dankama	0.6424	-0.0880	1.0185
Karofi	0.9343	-0.5376	-1.0044

Table 4. 10: Provenances Grouped into Clusters

Cluster	Provenances
1	Take Tsaba, Bakingada, Famfo, Kajiji, Burum, Maga, Masaya, Karofi, Dirbindai
2	Sabongarin Dabai, Jega Birni, Danjanku, Dankama, Gwarzo, Ruwan Kanya, Daki Takwas
3	Kwanan Maje, Soba
4	Tsaki, Kajiji, Kangire

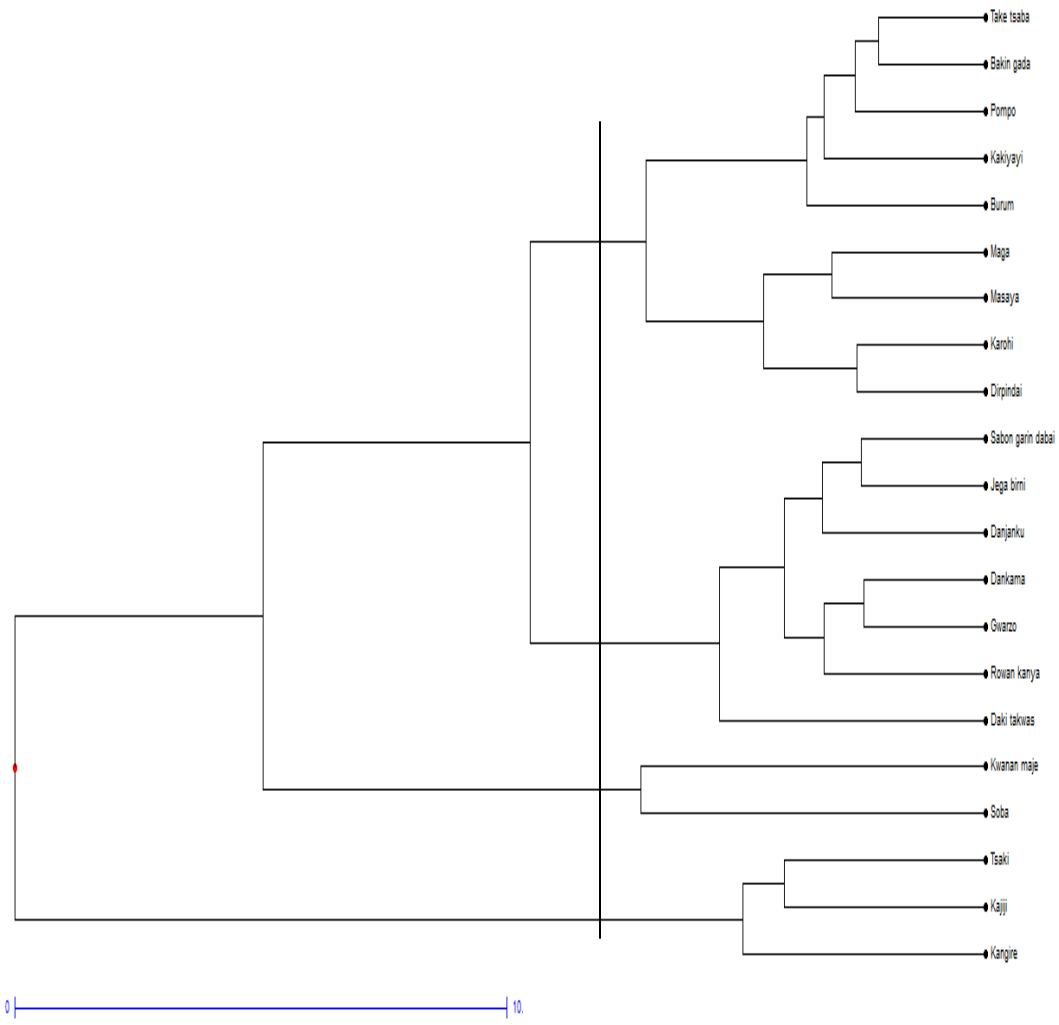


Figure 1: Dendrogram of provenance clusters based on nine morphological traits and oil content of 21 Jatropha curcas L. provenances collected across 7 states of the northwestern Nigeria

CHAPTER FIVE

5.0 DISCUSSION

The presence of highly significant differences among the 21 *Jatropha curcas* L. provenances suggests the presence of considerable genetic variability among the provenances for the traits studied. This is most likely because these provenances were sourced from different natural environments which might have been affected by natural selection. This indicates that significant improvement could be achieved through selection for the traits of interest. These observed variations therefore, present us with a raw material for breeding at a very early stage (germplasm collection) from base seed material that could be of use in improvement programmes especially considering the fact that *Jatropha curcas* L. is a relatively new crop in which crop breeding is still in its infancy in Nigeria. Provenances could be selected on the basis of distinguishable desirable traits and hybridized to obtain superior genotypes. Traits such as high number of lateral branches, high number of capsules per lateral branch and high number of fruit bunch per lateral branch indicate high quantity of fruits and ultimately high quantity of seeds per plant. This suggests that provenances with high number of lateral branches, high number of capsules per bunch and high number of fruit bunch per lateral branch could be selected for high seed yield on per plant basis. As number of lateral branches has significant phenotypic correlation with number of capsules per lateral branch as well as with number of capsules per bunch selection for one trait leads to the improvement of the other traits in the same direction. Plant height and number of lateral branches are important characters that can be looked upon as major selection indices when the objective is to incorporate Jatropha in an agro forestry system. The results indicated that plant height, number of branches on collar,

number of lateral branches, number of capsules per lateral branch and oil content were of high broadsense heritability while number of capsules per bunch has moderate broadsense heritability. Similar results were obtained by Rao *et al.* (2008) and Kaushik *et al*. (2007) who reported 99%broadsense heritability for oil content in *Jatropha curcas* L. This result shows that phenotypic selection for plant height, number of branches on collar, number of lateral branches, number of capsules per lateral branch and oil content as well as number of capsules per bunch is reliable as it indicates little environmental influence in determining the phenotype. This implies that the phenotype was a reflection of the genotype to a large extent in these traits. Generally, the high coefficients of range observed in most of the means of the morphological traits indicate that best provenances could be selected for each trait and as no single provenance possesses all the desirable traits, hybridization can give a desirable improved variety. Thus, as a strategy for obtaining superior *Jatropha curcas* L. trees possessing traits of interest, selection of provenances on the basis of the desirable traits followed by their hybridization will be very effective. This is in agreement with Clausen *et al.* (1948) who are on the view that hybrid from combining different provenances may result in hybrid vigor for many characters. Selection for traits that influence the seed yield is an indirect selection for high quantity of seeds obtainable from a tree. These traits include number of lateral branches, number of capsules per lateral branch, number of capsules per bunch and number of fruit bunch per lateral branch. Since flowers of the *Jatropha curcas* L. plant are only developed terminally, only plants with many branches (good ramification) can produce many fruits. A good plant should have bunches of *Jatropha curcas* L. fruits at every end of a branch. The highly significant phenotypic correlation between number of capsules per bunch with number of lateral branches as well as with number of capsules per lateral branch indicates that plants with good branching

habit tend to develop more number of capsules. This is in agreement with the work of Rao *et al.* (2008) who found a significant correlation between seed yield and number of branches and plant height. Similarly, the significant correlation between number of fruit bunch per lateral branch with number of capsules per lateral branch and number of capsules per bunch indicated that selection for any of the traits will indirectly result in high seed yield obtainable from a tree. The same applies to plant height and main stem height as they have highly significant correlation with each other showing that the two traits have strong association. The highly negative phenotypic correlations between collar height and collar thickness (r = -0.6715**) and between collar height and number of lateral branches (r = -0.6778**) indicated that increase in height of the collar will indirectly results in decrease in the collar thickness and number of lateral branches traits. The negative phenotypic correlation between collar height and number of capsules per lateral branches (r =-0.2631*) shows that increase in the collar height will also results in the decrease in the number of capsules per lateral branches. Increasing the number of branches on collar will also results in the decrease in both number of capsules per bunch and number of capsules per lateral branch. This is indicated by the negative significant phenotypic correlations between the number of branches on collar and number of capsules per bunch(r =-0.3445*) and between number of branches on collar and number of capsules per lateral branches (r =-0.3964*).The presence of significant phenotypic correlation between oil content and number of lateral branches shows that improving the number of lateral branches will be an improvement in oil content in *Jatropha curcas* L. This is in agreement with the findings of Rafii *et al*. (2012) who reported a positive correlation between oil content and number of branches in *Jatropha curcas* L. This positive phenotypic correlation can be explained by the fact that during the phonological succession of appearance of physiological and morphological

determinants of yield, the number of branches contributed to higher number of flower which in turn contributed to higher number of female flowers which finally culminated in higher yield.

Result from the rank summation index indicated that accessions IARJAT200901, IARJAT2009039 and IARJAT2009036 which were obtained from Soba, Gwarzo and Ruwan kanya provenances belonging to cluster 3 and 2 are the best materials in terms of plant height, number of lateral branches, number of fruit bunch per lateral branch, number of capsules per bunch and oil content. These accessions are therefore considered the best potential materials for the improvement of *Jatropha curcas* L. in Nigeria. Looking at the genetic distance, a cross between accessions IARJAT200901 and IARJAT2009039 obtained from Gwarzo and Soba provenances is recommended based on the rank summation index.

Principal component one is dominated by number of capsules per bunch number of capsules per lateral branch and number of fruit bunch per lateral branch which can be termed “bunch traits”. On principal component two, collar thickness, collar height and number of branches on collar which can be termed “collar traits” have the highest loadings. On principal component three however, main stem height and plant height are the main important traits (these can be called “height traits”). Thus, the principal component analysis was able to discriminate and separate the 21 *Jatropha curcas* provenances in terms of three dimensions. These were the bunch traits, collar traits and height traits axes. This result shows that the variations observed in the 21 provenances evaluated were in terms of these traits (bunch traits, collar traits and height traits). This implies that there is room for

improvement in these major traits. Depending on the breeding target, provenances can be selected from PC1, PC2 or PC3. If the target is high quantity of bunches, provenances from PC1 should be selected because it is dominated by bunch traits. This implies that Gwarzo and Tsaki with the highest loadings will be the best materials to be selected. When the target is collar traits, provenances from PC2 should be selected implying that Kwanan Maje and Burum are the best provenances. However, where the desire is height, Soba and Gwarzo from PC3 are the best provenances. Thus, for improvement in both bunch and height traits, hybridization between Soba and Gwarzo provenances is recommended as they belong to different clusters. Interestingly, this coincides with the result from Rank Summation Index.

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 Summary

Twenty one *Jatropha curcas* L. provenances collected from seven states of Northwestern Nigeria in 2009 were established in a provenance trial at the Institute for Agricultural Research (IAR) farm, Samaru in order to evaluate and determine their variation pattern, identify the major traits responsible for the variation and suggest potential provenances that could be used in the improvement of the crop in Nigeria. Data were taken on ten plants from each provenance in the cropping season of 2012 on ten morphological and oil content traits and analyzed.

All provenances showed highly significant variation except main stem height which showed significant variation at 0.05 level of probability. The existence of these variations in the provenances indicates the possibility of improvement through selection of provenances with desirable traits of interest. Mean performance showed significant difference for all traits with each trait exhibiting a considerable range. Number of capsules per bunch has significant phenotypic correlation with number of capsules per lateral branch as well as with number of fruit bunch per lateral branch. The number of fruit bunch per lateral branch also has significant phenotypic correlation with number of capsules per lateral branch. This result indicated that selection for any of these traits will indirectly results in high seed yield obtainable from a tree. The existence of highly significant genotypic correlation between oil content and number of capsules per bunch shows that

increasing the number of capsules per bunch will be an indirect improvement in the oil content.

Results from principal component analysis shows that three out of the ten principal components extracted had eigenvalue greater than one and altogether explained 77.07% of the total variability. Principal components 1, 2 and 3 exhibited 34.77%, 24.48% and 17.83% variabilities respectively among the provenances for the traits under study. Principal component 1 is associated with number of fruit bunch per lateral branch, number of capsules per bunch and number of capsules per lateral branch. Collar height, collar thickness and number of branches on collar were important for principal component 2. The third principal component however, was more related to plant height and main stem height. The principal component analysis therefore, discriminated and separated the 21 provenances in terms of bunch traits, collar traits and height traits indicating them to be the major traits responsible for the variation in the *Jatropha curcas* L. provenances. This shows that provenances can be selected from any of PC1, PC2 or PC3 depending on the breeding desire.

6.2 Conclusion

From rank summation index as computed according to Malumba and Mock (1978), accessions IARJAT200901, IARJAT2009039 and IARJAT2009036 which were obtained from Soba, Gwarzo and Ruwan kanya provenances are the best materials in terms of plant height, number of lateral branches, number of fruit bunch per lateral branch, number of capsules per bunch and oil content. These accessions are therefore considered the best

potential materials for the improvement of *Jatropha curcas* L. in Nigeria. However, considering the high genetic distance between accessions IARJAT200901 and IARJAT2009039 obtained from Soba and Gwarzo provenances belong to different clusters having high genetic distance, hybridization between the two provenances is recommended. This is also in agreement with the results from PCA.

6.3 Recommendation

Collection of more *Jatropha curcas* L. germplasm from all other zones of Nigeria and further research towards finding alleles for maximizing all desirable traits and pyramiding them into highly productive *Jatropha curcas* L. cultivars through breeding is recommended.

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