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Received: January 2, 2021

Accepted: March 4, 2021

Published: March 18, 2021

Citation: Tiendrébéogo KF, Sawadogo N, Gapili N, Ouédraogo MH, Ouédraogo RF, Nanema KR, Ouoba A, Sawadogo M. Variability and relationships between characters of physic nut (*Jatropha curcas* L.) in Burkina Faso. 2021 Mar 18;4:bs202106








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Data Availability Statement: All relevant data are within the paper and supplementary materials.

Funding: The authors have no support or funding to report.

Competing interests: The authors declare that they have no competing interests.

Variability and relationships between characters of physic nut (*Jatropha curcas* L.) in Burkina Faso

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Abstract

Jatropha curcas is a highly promising species for biodiesel production in Burkina Faso and other countries in the tropics. It is rustic, grows in warm regions and is easily cultivated. These characteristics and high-quality oil yields from the seeds have made it a priority for biodiesel programs. Consequently, this plant merits genetic investigations aimed at improving yields. The present study was conducted to determine the extent of genetic variability and relationships among 30 accessions from Burkina Faso using 7 qualitative characters and 20 quantitative characters. For most of the traits, there were highly significant differences among the accessions. A positive and significant correlation between the 100-seed weight trait and the oil content trait was observed. The oil content trait is significantly and positively influenced by growth traits such as plant height and crown diameter. Based on the petiole base pigmentation, three morphotypes were identified: green morphotype, purple morphotype and brown morphotype. The green morphotype was characterized by very high oil content and high 100-seed weight while the brown morphotype presents low oil content and low 100-seed weight. The purple morphotype registered a high oil content and medium 100-seed weight. These results are important for the continuity of breeding programs, aimed at obtaining cultivars with high grain yield and high oil content in seeds.

Keywords: Oil content, Genetic diversity, Genetic correlation, Morphotype, *Jatropha curcas*, Burkina Faso.

Introduction

Physic nut (*Jatropha curcas* L.) is a perennial oil plant commonly used in tropical areas as a medicinal plant, in the construction of defensive hedges against animals and in the fight against water erosion [1]. It is rustic, grows in warm regions and is easily cultivated. These characteristics and high-quality oil yields from the seeds have made this plant a priority and a highly promising species for biodiesel programs in countries in the tropics [2]. It produces seeds rich in oil which can be used pure after filtration as fuel in diesel engines with indirect injection or serve as raw material for the production of biodiesel by transesterification [3, 4]. [5] highlighted the economic interest of the use of oil of this species for the poor countries, in particular tropical Africa and Asia. Indeed, *J. curcas* provides various products that contribute to poverty reduction, in particular the promotion of income-generating activities mainly for women such as sale of seeds and soap and the valuation of oil cakes as organic fertilizers. It is an opportunity for developing countries to improve farmers' incomes and even stimulate the rural economy [6]. However, in most countries of sub-Saharan Africa, the establishment of plantations preceded the conduct of agronomic research essential for the sustainable exploitation of the plant. As a result, plant development has been poor and yields obtained during the first years of cultivation have generally been disappointing [7]. Consequently, this species merits genetic investigations aimed at improving yields [2]. So, the viability of the *J. curcas*-based biodiesel sector is essentially based on highly productive and oil-rich *J. curcas* genotypes [6].

Despite strong recommendations for improvement of *J. curcas* for intensive production, a very little references exist on the genetic characteristics of the plant, the level of productivity of *J. curcas* in relation to its genetic potential and the cultivation techniques [6]. Indeed, *J. curcas* is still essentially a wild plant which must be the object of genetic improvement and domestication for its popularization and vaolrization [8, 9]. In Burkina Faso, the genetic diversity of the species remains still poorly known [10-13]. Thus, within the framework of the promotion of the neglected or under-exploited local species, this study was initiated in order to contribute to a better knowledge the genetic diversity and the relationships between agro-morphological traits and seeds oil content of *J. curcas*.

Material and methods

Plant material

The plant material consisted of 30 elite accessions selected by [11] based on the morpho-metric characteristics of the fruits as well as the oil content of the seeds. In this study, an accession is a set of seeds, from natural pollination, harvested from the same tree during prospecting. The seeds were stored at laboratory temperature without any prior chemical treatment.

Experimental site

The agro-morphological characterization was carried out on a plantation installed in the experimental station of the Institute for Rural Development (IDR) of Gampela at 1°21'0.9" West longitude, 12°24'10.7" North latitude and 924 m altitude. The station is characterized by very heterogeneous, deep soils, of low physicochemical fertility and a predominantly sandy-clay texture [14]. The climate of the zone is of the sudano-sahelian type characterized by the alternation of two seasons, namely a rainy season which extends from june to october and a dry season from november to may [15]. The annual rainfall recorded in the station during the experimentation varied between 728 and 984.8 mm. Average air temperatures during the rainy months range between 35° C and 40° C for the maximums and between 18° C and 19° C for the minimums [15].

Experimental design

The experimental design used is a completely random experiment plan consisting of 30 elementary plots of 8 m x 8 m. Each elementary plot contains 9 plants arranged in three lines of 8 m in length each. The spacing between the lines was 4 m. Each line includes three plants with a spacing of 4 m. The aisles between the elementary plots were also 4 m.

Characters studied

Qualitative characters

Based on the work of [16], seven qualitative variables were chosen to characterize the phenotypic variability of the accessions studied. The Table 1 presents the different characters with their modalities.

Table 1. Modalities of qualitative traits.

Variables	Modalities
Branching pattern	Basal
	Intermediate
	Top
	Entire
Petiole base pigmentation	Green
	Brown
	Purple
Stem colour	Green
	Grey
Leaf colour	Green
	Light green
	Dark green
Latex colour	Cream
	Red
Phyllotaxy	Alternate
	Whorled
Growth habit	Shrub (< 5 m)
	Tree (> 5m)

Quantitative characters

Based on the work of [17, 2, 18, 16, 6], 20 quantitative variables were chosen to characterize the genetic diversity of *J. curcas* five years after planting. These parameters were measured on three plants sampled by accession. These are first of all the parameters linked to the vegetative development of the trees, measured three months after the appearance of the first leaves. Those are:

- The dendrometric characters of trees such as plant height (PH) measured from the base to the apex of the main stem, crown diameter (CD) measured between both ends of the plant, stem diameter (SD) measured at the collar using a tape measure ($SD = \text{collar circumference} / \pi$) and number of main branches (NB) evaluated by counting the branches coming out from the trunk .
- The characters linked to the dimensions of the leaves measured on three fresh leaves, fully developed and not parasitized, per individual: these were the width of the leaf (WL) measured between the two ends of the leaf, the length of the leaf (LL) measured from the petiole to the tip of the leaf and the length of the petiole (LP) measured from the insertion of the stem to the insertion of the leaf.

The traits linked to the productivity of the accessions such as fruits weight (FRW), seeds weight (SEW) and pulps weight (PUW) per accession were also evaluated at the ripe and dry fruit stage using an electric scale. Moreover, others traits relative to the fruits were measured. They are the average length of the fruit (ALF), the average diameter of the fruit (ADF) evaluated using a digital caliper, the average weight of the fruit (AWF) and the average weight of the pulp (AWP) determined using an electric

scale on ten fruits. The average number of seeds per fruit (ANS) was determined by counting.

As concerning the seeds, the characters measured were the 100-seed weight (SW100) determined by weighing a random sample of 100 seeds of each mother plant using an electric scale, the average length of the seed (ALS), the average width of the seed (AWS) and the average thickness of the seed (ATS) measured with a digital caliper on ten seeds. The seeds oil content (OIL) was determined by the soxhlet extraction method using hexane as the solvent [19]. [16] proposed a descriptor with four classes based on the seeds oil content character in relation with the weight of the seed: low (0-20%), medium (21-30%), High (31-40%) and very high (> 40%).

Data analysis

The data collected were analyzed with XLSTAT 2020.3.1.11 software. Analysis of variance (ANOVA) and of Student Newman Keuls means separation test at $\alpha=5\%$ were carried out in order to compare accessions. Pearson's R coefficient was used to measure correlations between quantitative traits while the relationships between discriminate qualitative and quantitative traits were determined through multiple correspondence analysis (MCA). Indeed, the quantitative traits have been previously transformed into qualitative traits according to the classes obtained in the Student Newman Keuls means separation test.

Results

Analysis of the phenotypic variability of *J. curcas* using qualitative variables

The results recorded in Table 2 showed that all the accessions studied had green stems and green leaves, a cream-colored latex and alternate leaves. However, two characters presented variability. Thus, the majority of plants (70%) had a basal branching pattern while a minority (30%) revealed an intermediate branching pattern (Figure 1). The petiole base expressed several pigmentation color (Figure 2): green (33.33%), brown (13.33%) and mostly purple (53.34%).

Analysis of the phenotypic variability of *J. curcas* using quantitative variables

The results of the significance of the means separation test of Newman Keuls were performed with vegetative development parameters (Table 3), fruit parameters (Table 4) and seeds parameters (Table 5). Most of the vegetative development parameters and seeds traits significantly discriminate the accessions studied except the length of the petiole (LP), the average length of the seed (ALS) and seeds weight per accession (SEW). For the fruit traits, only three of the seven measured characters, precisely the average length of the fruit (ALF), the average weight of the fruit (AWF) and the average weight of the pulp (AWP) showed variability. Based on the each of three characters of interest namely oil content (OIL), 100-seed weight (SW100) and crown diameter (CD), three classes were obtained within accessions. Indeed, according to the value of the character, three performance classes

Table 2. Variation in the qualitative characters of the collection of *J. curcas*.

Variables	Modalities	Frequencies (%)
Branching pattern	Basal	70
	Intermediate	30
	Top	0
	Entire	0
Petiole base pigmentation	Green	33.33
	Brown	13.33
	Purple	53.34
Stem colour	Green	100
	Grey	0
Leaf colour	Green	100
	Light green	0
	Dark green	0
Latex colour	Cream	100
	Red	0
Phyllotaxy	Alternate	100
	Whorled	0
Growth habit	Shrub (< 5 m)	100
	Tree (> 5m)	0

(low, medium, high) were registered with the 100-seed weight trait and crown diameter, respectively. The seeds oil content character showed also three performance classes which ranged medium, high and very high according to the descriptor classes.

Relationships between characters

Correlation between characters

The correlation of Pearson (Table 6) showed positive and significant correlations at the 5% and 1% threshold between the characters studied. Thus, the character oil content was positively correlated with the characters 100-seed weight ($r = 0.253$), plant height ($r = 0.344$) and crown diameter ($r = 0.260$). The 100-seed weight character was positively correlated with the characters linked to vegetative development such as plant height ($r = 0.522$), crown diameter ($r = 0.443$) and length of the petiole ($r = 0.272$). Furthermore, the crown diameter character is positively correlated with all the other characters studied. These different correlations indicate that plants with significant vegetative development produce seeds of high weight and high oil content. The characters linked to the yield (FRW, SEW and PUW) are positively correlated with the characters relating to the scale of the plant (PH, SD and CD). So, large-scale plants have also high productive potential. Furthermore, the characters of the seeds (ALS, AWS and ATS) are positively influenced each other.

Association between characters

The results of multiple correspondence analysis (MCA) recorded in Figure 3 showed three associations of the characters. On the plan formed by axes 1 and 2 with 45.41% of the total inertia, the F1 axis (23.14% of total inertia) opposed two groups of variables precisely group 1 and group 3. Group 1 combined the characters very high seed oil content (> 40%), intermediate



Figure 1. Branching pattern of *J. curcas*. **A:** Basal (70%), **B:** Intermediate (30%).



Figure 2. Petiole base pigmentation of *J. curcas* **A:** Green (33.33%), **B:** Brown (13.33%), **C:** Purple (53.34%)

Table 3. Results of Newman Keuls' means separation test on vegetative development parameters.

Accession	PH (m)	SD (cm)	CD (m)	NB	WL (cm)	LL (cm)	LP (cm)
1	2.450 bcde	9.076 b	2.650 abc	4.000 b	16.295 abc	14.365 abc	20.165 a
2	1.977 cde	15.711 ab	2.733 abc	6.333 ab	15.130 abc	14.127 abc	17.197 a
3	2.600 bcd	12.527 ab	3.100 abc	5.667 ab	15.040 bc	13.477 abc	17.007 a
4	2.747 b	13.896 ab	3.717 ab	6.000 ab	17.207 abc	15.497 abc	18.997 a
5	2.490 bcde	15.977 ab	3.467 abc	6.000 ab	14.410 c	13.930 abc	17.167 a
6	2.150 bcde	13.694 ab	3.350 abc	5.500 ab	15.545 abc	13.545 abc	18.430 a
7	2.033 bcde	13.694 ab	3.000 abc	5.000 ab	17.477 abc	14.720 abc	16.983 a
8	2.567 bcd	13.907 ab	3.133 abc	5.000 ab	18.850 ab	16.687 a	18.430 a
9	2.567 bcd	14.756 ab	3.150 abc	5.667 ab	18.463 ab	15.710 abc	19.820 a
10	2.383 bcde	12.909 ab	3.000 abc	5.667 ab	16.597 abc	14.797 abc	16.943 a
11	2.017 bcde	12.707 ab	2.857 abc	7.667 ab	16.333 abc	14.043 abc	16.863 a
12	3.225 a	13.854 ab	3.500 abc	9.000 a	18.415 ab	15.930 ab	19.195 a
13	2.100 bcde	12.739 ab	2.800 abc	5.000 ab	14.895 bc	12.460 c	14.945 a
14	2.233 bcde	14.862 ab	3.150 abc	6.000 ab	17.283 abc	14.997 abc	16.710 a
15	2.017 bcde	15.287 ab	2.733 abc	8.000 ab	16.763 abc	14.517 abc	15.467 a
16	2.047 bcde	15.287 ab	2.900 abc	5.333 ab	16.177 abc	13.410 abc	16.310 a
17	2.227 bcde	13.163 ab	3.167 abc	4.667 ab	16.553 abc	14.483 abc	18.073 a
18	2.275 bcde	15.287 ab	3.450 abc	8.000 ab	16.350 abc	15.015 abc	18.795 a
19	2.683 bc	13.376 ab	4.000 a	6.333 ab	18.997 a	16.630 a	19.553 a
20	2.340 bcde	13.641 ab	3.400 abc	4.333 ab	16.693 abc	14.753 abc	18.310 a
21	2.225 bcde	13.694 ab	2.900 abc	9.000 a	17.545 abc	14.910 abc	18.130 a
22	2.417 bcde	12.781 ab	2.867 abc	7.000 ab	16.910 abc	14.340 abc	17.517 a
23	1.915 de	10.987 ab	2.650 abc	4.000 b	15.530 abc	12.900 bc	13.995 a
24	1.900 de	14.411 ab	2.635 abc	7.000 ab	15.965 abc	14.130 abc	18.365 a
25	1.770 e	10.403 ab	2.100 c	5.667 ab	15.387 abc	12.683 bc	15.297 a
26	2.267 bcde	10.032 ab	2.600 abc	3.667 b	17.940 abc	15.440 abc	17.097 a
27	1.857 de	12.951 ab	2.400 bc	5.667 ab	14.953 bc	12.730 bc	14.617 a
28	2.183 bcde	16.561 ab	2.767 abc	7.000 ab	16.217 abc	13.463 abc	16.410 a
29	1.880 de	17.304 a	2.767 abc	6.000 ab	15.573 abc	13.797 abc	15.750 a
30	1.900 de	11.996 ab	2.700 abc	4.333 ab	16.420 abc	14.697 abc	16.017 a

PH: plant height, SD: stem diameter, CD: crown diameter, NB: number of main branches,

WL: width of the leaf, LL: length of the leaf, LP: length of the petiole.

The values for each class followed by the same letters are not significantly different at the 5% level.

branching of the stem, green pigmentation of the petiole base, high 100-seed weight (≥ 62.85 g) and large crown diameter (≥ 4 m) while the group 3 is formed by association between the medium oil content (21-30%), the brown pigmentation of the petiole base and the low 100-seed weight (≤ 36.9 g). Group 2,

correlated to axis F2 with 22.127% of total inertia, combined the high oil content (31-40%), the basal branching of the stem, the purple pigmentation of the petiole base, the medium 100-seed weight (43.30-43.85 g), the medium crown diameter (2.4-3.467 m) and the small crown diameter (≤ 2.1 m).

Table 4. Results of Newman Keuls' means separation test on fruits parameters.

Accession	ALF (cm)	ADF (cm)	AWF (g)	AWP (g)	ANS	FRW (g)	PUW (g)
1	2.533 ab	2.110 a	2.610 ab	0.940 ab	2.550 a	158.400 a	49.900 a
2	2.265 ab	2.058 a	1.843 ab	0.790 abcd	2.500 a	207.233 a	94.867 a
3	2.425 ab	2.120 a	2.623 ab	0.920 abc	2.700 a	263.167 a	93.567 a
4	2.457 ab	2.080 a	2.460 ab	0.873 abc	2.800 a	509.200 a	189.900 a
5	2.340 ab	2.053 a	2.430 ab	0.837 abcd	2.833 a	541.667 a	211.600 a
6	2.468 ab	2.083 a	2.710 ab	1.005 a	2.950 a	816.250 a	317.450 a
7	2.383 ab	2.090 a	1.840 ab	0.670 bcd	2.200 a	136.967 a	56.733 a
8	2.478 ab	2.158 a	2.120 ab	0.757 abcd	2.467 a	163.767 a	68.467 a
9	2.535 ab	2.100 a	2.277 ab	0.837 abcd	2.667 a	463.867 a	210.133 a
10	2.425 ab	2.117 a	2.143 ab	0.720 abcd	2.500 a	249.433 a	100.367 a
11	2.402 ab	2.067 a	2.300 ab	0.930 abc	2.633 a	248.233 a	114.567 a
12	2.430 ab	2.140 a	2.500 ab	0.830 abcd	2.750 a	453.500 a	168.300 a
13	2.498 ab	2.035 a	2.175 ab	0.895 abc	2.850 a	641.400 a	256.050 a
14	2.483 ab	2.078 a	2.133 ab	0.880 abc	2.567 a	433.867 a	172.033 a
15	2.130 b	1.998 a	1.417 b	0.547 d	2.367 a	174.767 a	79.533 a
16	2.567 a	2.158 a	2.773 a	0.877 abc	2.967 a	496.000 a	190.900 a
17	2.425 ab	2.045 a	2.120 ab	0.750 abcd	2.600 a	384.400 a	161.667 a
18	2.593 a	2.145 a	2.530 ab	0.770 abcd	2.850 a	834.300 a	277.150 a
19	2.395 ab	2.093 a	2.493 ab	0.750 abcd	2.967 a	774.267 a	287.667 a
20	2.397 ab	2.078 a	2.380 ab	0.750 abcd	2.833 a	836.400 a	323.800 a
21	2.420 ab	2.073 a	2.115 ab	0.660 bcd	2.750 a	158.850 a	59.700 a
22	2.393 ab	2.112 a	1.940 ab	0.733 abcd	2.533 a	162.800 a	73.567 a
23	2.460 ab	2.088 a	2.015 ab	0.670 bcd	2.600 a	99.600 a	39.100 a
24	2.330 ab	1.940 a	1.770 ab	0.607 cd	2.230 a	86.400 a	37.350 a
25	2.205 ab	1.927 a	1.627 ab	0.608 cd	2.420 a	89.200 a	39.600 a
26	2.380 ab	2.083 a	1.797 ab	0.713 abcd	2.133 a	64,933 a	29.600 a
27	2.212 ab	1.978 a	1.537 ab	0.637 bcd	2.200 a	97.867 a	49.033 a
28	2.368 ab	2.088 a	1.830 ab	0.833 abcd	2.333 a	147.533 a	71.133 a
29	2.245 ab	1.945 a	1.800 ab	0.870 abc	2.100 a	89.300 a	40.000 a
30	2.192 ab	2.043 a	1.607 ab	0.843 abcd	2.067 a	78.100 a	43.933 a

ALF: average length of the fruit, ADF: average diameter of the fruit, AWF: average weight of the fruit,

AWP: average weight of the pulp, ANS: average number of the seeds per fruit,

FRW: fruits weight per accession, PUW: pulps weight per accession.

The values for each class followed by the same letters are not significantly different at the 5% level.

Table 5. Results of Newman Keuls' means separation test on seeds parameters.

Accession	ALS (cm)	AWS (cm)	ATS (cm)	SW100 (g)	SEW (g)	OIL (%)
1	1.830 a	1.120 ab	0.863 ab	56.100 ab	108.500 a	33.811 i
2	1.755 a	1.092 ab	0.835 ab	47.833 abc	112.367 a	31.160 lm
3	1.803 a	1.150 ab	0.868 a	63.350 a	169.600 a	35.897 g
4	1.833 a	1.113 ab	0.855 ab	62.850 a	319.300 a	34.663 h
5	1.753 a	1.068 b	0.818 ab	55.833 ab	330.067 a	39.286 c
6	1.845 a	1.173 a	0.853 ab	61.100 ab	498.800 a	31.309 l
7	1.813 a	1.092 ab	0.847 ab	55.600 ab	80.233 a	35.023 h
8	1.833 a	1.123 ab	0.865 ab	52.900 abc	95.300 a	32.874 j
9	1.890 a	1.068 b	0.835 ab	53.300 abc	253.733 a	37.931 e
10	1.827 a	1.098 ab	0.873 a	54.933 ab	149.067 a	35.474 g
11	1.753 a	1.130 ab	0.850 ab	54.450 ab	133.667 a	37.989 e
12	1.780 a	1.073 b	0.845 ab	63.700 a	285.200 a	37.931 e
13	1.753 a	1.065 b	0.813 ab	43.850 bc	385.350 a	32.360 k
14	1.868 a	1.060 b	0.835 ab	48.500 abc	261.833 a	40.383 b
15	1.688 a	1.063 b	0.813 ab	45.900 abc	95.233 a	31.331 l
16	1.840 a	1.118 ab	0.852 ab	58.333 ab	305.100 a	29.366 o
17	1.792 a	1.107 ab	0.825 ab	55.233 ab	222.733 a	31.577 l
18	1.813 a	1.120 ab	0.870 a	64.300 a	557.150 a	32.486 jk
19	1.832 a	1.152 ab	0.857 ab	59.200 ab	486.600 a	40.863 a
20	1.765 a	1.125 ab	0.832 ab	63.250 a	512.600 a	34.726 h
21	1.840 a	1.118 ab	0.853 ab	52.450 abc	99.150 a	30.800 mn
22	1.805 a	1.065 b	0.832 ab	64.000 a	89.233 a	32.463 jk
23	1.808 a	1.088 ab	0.828 ab	54.400 ab	60.500 a	32.760 jk
24	1.740 a	1.090 ab	0.868 ab	43.300 bc	49.050 a	30.474 n
25	1.663 a	1.070 b	0.800 b	50.200 abc	49.600 a	34.040 i
26	1.780 a	1.113 ab	0.847 ab	53.200 abc	35.333 a	36.909 f
27	1.707 a	1.065 b	0.817 ab	51.600 abc	48.833 a	38.640 d
28	1.782 a	1.060 b	0.832 ab	43.500 bc	76.400 a	31.617 l
29	1.672 a	1.067 b	0.837 ab	47.100 abc	49.300 a	35.549 g
30	1.687 a	1.112 ab	0.853 ab	36.900 c	34.167 a	28.137 p

ALS: average length of the seed, AWS: average width of the seed,

ATS: average thickness of the seed, SW100: 100-seed weight,

SEW: seeds weight per accession, OIL: seeds oil content.

The values for each class followed by the same letters are not significantly different at the 5% level.

Table 6. Matrix of correlations between the studied characters.

Variables	ALF	ADF	AWF	AWP	ANS	ALS	AWS	ATS	SW100	OIL	PH	SD	CD	NB	WL	LL	LP	FRW	SEW
ADF	0.787**																		
AWF	0.745**	0.627**																	
AWP	0.588**	0.493**	0.706**																
ANS	0.598**	0.550**	0.836**	0.469**															
ALS	0.860**	0.787**	0.613**	0.433**	0.509**														
AWS	0.391**	0.463**	0.520**	0.359**	0.418**	0.432**													
ATS	0.423**	0.402**	0.392**	0.316**	0.041	0.470**	0.521**												
SW100	0.392**	0.350**	0.570**	0.191	0.428**	0.324**	0.320**	0.226*											
OIL	0.076	0.012	0.155	0.089	0.100	0.140	-0.062	-0.053	0.253*										
PH	0.418**	0.413**	0.499**	0.277*	0.387**	0.459**	0.186	0.326**	0.522**	0.344**									
SD	0.067	0.097	0.102	0.194	0.070	0.059	-0.175	0.116	0.057	-0.019	0.133								
CD	0.387**	0.428**	0.552**	0.370**	0.501**	0.402**	0.312**	0.301**	0.443**	0.260*	0.651**	0.460**							
NB	-0.010	-0.018	0.038	0.016	0.093	0.001	-0.105	0.125	0.024	0.025	0.189	0.379**	0.225*						
WL	0.143	0.160	0.002	-0.171	-0.027	0.260*	0.029	0.261*	0.047	0.172	0.429**	0.039	0.317**	0.022					
LL	0.133	0.208	0.088	-0.067	0.047	0.265**	0.116	0.355**	0.095	0.210	0.546**	0.159	0.455**	0.089	0.843**				
LP	0.183	0.108	0.266*	0.061	0.221*	0.265**	0.208	0.234*	0.272*	0.108	0.550**	0.096	0.394**	0.069	0.530**	0.641**			
FRW	0.426**	0.325**	0.524**	0.345**	0.556**	0.350**	0.258*	0.134	0.410**	0.149	0.464**	0.308**	0.675**	0.141	0.039	0.168	0.293**		
SEW	0.424**	0.318**	0.527**	0.332**	0.554**	0.344**	0.269*	0.147	0.427**	0.149	0.473**	0.286**	0.667**	0.136	0.045	0.175	0.307**	0.997**	
PUW	0.425**	0.333**	0.512**	0.363**	0.554**	0.356**	0.235*	0.111	0.375**	0.148	0.443**	0.339**	0.680**	0.146	0.027	0.154	0.266*	0.992**	0.98**

ALF: average length of the fruit, ADF: average diameter of the fruit, AWF: average weight of the fruit, AWP: average weight of the pulp, ANS: average number of the seeds per fruit, ALS: average length of the seed, AWS: average width of the seed, ATS: average thickness of the seed, SW100: 100-seed weight, OIL: seeds oil content, PH: plant height, SD: stem diameter, CD: crown diameter, NB: number of main branches, WL: width of the leaf, LL: length of the leaf, LP: length of the petiole, FRW: fruits weight per accession, SEW: seeds weight per accession, PUW: pulps weight per accession, * Significantly at 5%, ** Significantly at 1%.

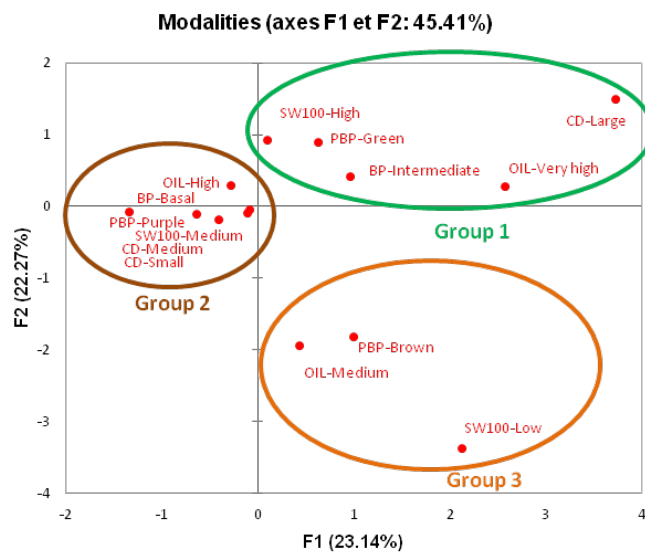


Figure 3. Association of modalities of traits in the 1/2 plan of the multiple correspondence analysis (MCA) (45.41%). BP: branching pattern, PBP: petiole base pigmentation, OIL: oil content, SW100: 100-seed weight.

Discussion

The agro-morphological evaluation using quantitative and qualitative characters highlighted the existence of variability for some characters. Similar results for quantitative traits were obtained by [20] and [11, 12]. For qualitative characters, this variability relates to branching pattern and petiole base pigmentation. [16] reported similar results on the petiole base pigmentation. However, only two types of stem branching were observed in this study compared to four types obtained by these same authors, thus indicating that the accessions studied are less diversified for this character. No color variation was noted on the stems and leaves of the studied accessions. These results are similar to those of [17], [21] and [22] but differ from those of [16]. Genetic correlations indicate genetic relations between characters. Knowledge of correlations among the characters is useful in designing an effective breeding program for any crops [23]. Indeed, the magnitude and direction of the genetic correlation is important in the choice of breeding methods and the formulation of strategies for simultaneous selection on multiple traits [2]. The correlations noted in this study corroborate those observed by [2] and [23]. In this study, statistically significant correlation of oil content existed with crown diameter and plant height. In addition, 100-seed weight character is significantly correlated with crown diameter, petiole length and plant height. These correlations are interesting for improvement programs because according to [24], the selection of elite accessions to reproduce for oil extraction should be oriented towards those with the best crown and seed weight traits. Furthermore, [25] indicate that the quantity of seeds produced on the one hand is positively correlated with crown, and on the other hand the seed weight

and the oil content are positively correlated. Significant and positive correlations between the characters of the seeds would favor the simultaneous improvement of these characters through selection. Thus, in the study, interesting correlations were noted between the characters linked to the weight and dimensions of the seeds. The strong positive correlation between the characters of the seeds indicates that the genes which govern these characters are probably linked or have a pleiotropic effect. Similar results have been reported by [2] and [23] between 100-seed weight and the dimensions of the seed. However, the study found no significant correlation between the oil content and the dimensions of the seeds studied. Similar results have been also reported by [2] and [18]. Furthermore, the study showed a positive and significant correlation between the 100-seed weight trait and the seed oil content trait. [26] and [23] observed a positive and significant correlation between seed weight and oil content while [27] revealed a negative correlation between these two characters. [18] indicated that these contrasting results could be explained by the high weight of the seed coat of some accessions. According to [16], qualitative characters are morphological markers that can be used to identify lines in a relatively short time. These authors reported also that the development of descriptors on perennial plants such as *J. curcas* can contribute to an effective use of germplasm in the improvement programs. Analysis of the association of characters revealed the existence of three morphotypes differing in the color of the pigmentation of the base of the petiole, the oil content of the seeds and 100-seed weight. [16] identified also three descriptors based on the pigmentation of the petiole base. For perennial plant such as *J. curcas*, these morphological descriptors could make it possible to select genotypes with high productive potential in the short term. According to [23], complex plant characters such as yield are quantitatively inherited and influenced by genetic effects, as well as by genotype and environment interaction and selection may be difficult and time consuming to improve yield directly especially for perennial crops such as *J. curcas*. Therefore, identification and use of associations between characters are appropriate. In this study, statistically significant association of 100-seed weight existed with seed oil content. Therefore, seed weight can be considered as important character for early selection of seed sources. Furthermore, according to [11], the characters 100-seed weight and oil content showed the highest values of broad-sense heritability (83.23% and 99.93% respectively) and high expected genetic advance (22.63% and 19.62% respectively). The high broad-sense heritability values associated with high expected genetic advance indicate that effects of the genes are of additive type for these characters and the opportunities to improve seed weight character and oil content character through the selection.

Conclusion

This study highlighted an important agro-morphological diversity within the accessions of *J. curcas* from Burkina Faso. The variability observed within the accessions studied and the as-

sociations between the characters obtained constitute a database for the genetic improvement programs of *J. curcas* in Burkina Faso, in particular the development of high-yielding cultivars. A positive and significant correlation between the 100-seed weight trait and the oil content trait was noted. Growth traits such as plant height and crown diameter was also significantly and positively correlated with the oil content trait. Three morphotypes were identified using petiole base pigmentation which are the green morphotype with very high oil content and high 100-seed weight, the purple morphotype with medium oil content and medium 100-seed weight and finally the brown morphotype with low oil content and low 100-seed weight. For perennial plant such as *J. curcas*, these results on relationships between characters could make it possible to select genotypes with high productive potential in the short term.

Acknowledgments

The authors gratefully acknowledge the Bioscience Laboratory precisely Genetic and Plant Breeding Team (EGAP) of the «Université Joseph KI-ZERBO» for the financial support of this work. They are also thankful to all team members of the Bioscience Laboratory for their input in this manuscript.

Authors' Contributions

This work was carried out in collaboration between both authors. The two first authors designed the experiment and analyzed the data. Both of the authors interpreted the data, read the final manuscript, and agreed with all contents.

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