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A study of the variability for grain and oil yield and yield related traits of castor beans accessions in two savannah agro-ecological zones of Cameroon

T. L. Tchuenteu, C. Megueni*, Y. N. Njintang

Department of Biological Sciences, Faculty of Sciences, University of Ngaoundéré, Cameroon

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Abstract

Field trials were carried out to investigate the seeds/oil yielding ability and yield related traits of three accessions of castor beans (Motso 1, Motso 2 and Ndoutourou) cultivated in the environmental conditions of the two agro-ecological zones of Northern Cameroon (Sudano-guinea zone and Sudano-sahelian zone). Planting was done following a randomized block design with 3 replications and three treatments (Castor bean accessions) in each of these study zones. The growing parameters, the seeds yield and oil yield were evaluated. Growing parameters and seeds and oil yields were significantly different ($p<0.05$) between castor bean accessions and the two study zones. Castor bean accessions adapted better in the Sudano-Guinea zone than the Sudano-sahelian zone. Irrespective of the growing zone, Ndoutourou accession possessed the highest seeds and oil yield, 4.09±0.004 and 4.28±0.02 t ha^{-1} respectively in Sudano-Guinea zone and Sudano-Sahelian zone) is more than those of Motso 1 and Motso 2 accessions. Motso 1 accession has the smallest seeds yield. It comes out from these results that Ndoutourou accession can be recommended to farmers of Northern Cameroon to be integrated into their agricultural systems.

* **Corresponding Author:** C. Megueni ✉ tatchumlucien@yahoo.fr

Introduction

Castor bean (*Ricinus comminus* L.) is an oleaginous (40-60% oil) cultivated for its seeds which yield viscous, pale and non-volatile yellow oil (Pina *et al.*, 2005). The oil has many industrial applications notably it is used in the manufacture of paints, dyes, inks, waxes, varnishes, lubricants and brake fluids (Devendra and Raghavan, 1978; Ramos *et al.*, 1984; Ogunniyi, 2006). The castor oil obtained by cold pressing of seeds is also used in household for soap production and as purgatives and laxatives (Weiss, 2000). Castor plant is cultivated industrially in many countries like India, China, Brazil, Madagascar (Pina *et al.*, 2005). However India alone exports 0.73 Mt of castor seeds per year accounting to 60% of the total world production and therefore largely dominates the market. Despite the more and more increasing production, the demand for castor beans in the world market steadily increases (Sujatha *et al.*, 2008), then given opportunity to improve and increase castor beans production. In this respect Reddy and Matcha (2010) suggested that castor bean crop can become a cash crop in modern agriculture. Studies have been initiated in this direction to introduce and study the adaptability of castor bean in different soil of several countries including USA (Baldwin and Cossar, 2009) and in Europe (Laureti and Marras, 1995; Koutroubas *et al.*, 1999). Such study seems to be not undertaken under savannah climate, at the best of our knowledge. Yet, Castor bean (*Ricinus communis* L.), a C3 plant has been dedicated to be native of tropical Africa (Baldwin and Cossar, 2009).

In the perspective to explore the feasibility of castor oil as an alternative cash crop in Cameroon, questions on the growing performance of available accessions in the savannah regions needs to assess. Castor plant has been demonstrated to growth well in little shade environments where there is soil rich in organic manure, well drained and possessing neutral pH (Weiss, 2000). Castor bean yield also depend on the latitude and management practices (Oplinger *et al.*, 1990). The seed oil content depends on the genotype, but it is also affected by the environmental conditions, cultural practices and time of harvesting. Koutroubas *et al.* (1999) investigated the adaptation and yield of 19 castor bean plants genotypes and observed that the plant height depend mainly on the genotype, the site and the year of the experimentation. High temperatures, above 35°C, and water stress during the flowering and oil formation can reduce the seed oil content (Weiss, 1983). One of the most important factors affecting the seeds oil content is the variety, and in this respect Ramos *et al.* (1984) surveyed 36 castor bean varieties in Brazil for oil and fatty acid composition and revealed a large variability of seed oil percentage ranging from 39.6% to 59.5%.

Castor bean cultivation is not popularized in sub-Saharan Africa. Recent investigation on castor beans available in Cameroon revealed the presence of some accessions in the sudano-guinea and sudano-sahelian savannah zones where they are used as fence (Tchobsala, 2008) and /or soil fertilisation (Azim, 2005). Tchobsala (2008) listed 16 accessions of castor bean in North Cameroon. Djonbada (2010) investigate the agronomics characteristics of these castor bean accessions in field in North Cameroon and 3 of them named Motso 1, Motso 2 and Ndoutourou were identified as the best seeds yielding accessions. The savannah area seems to be favorable to castor production; however no information exists on their performance under this climate since the environmental conditions are determinant factors conditioning their growth and seed yield. The agronomies characteristics and oil content of castor bean from other countries such as Brazil, Nigeria, India and China had been studied. The agronomic characteristics of these local castor bean accessions cultivated in field in Adamawa and Maroua regions (Cameroon), the seeds oil content from these areas, as well as the influence of these localities on these parameters are not known. The research question on this study concerned then the evaluation of the performance of 3 local accessions of castor beans in 2 agro-ecological savannah zones of Cameroon. In other words what are the height, the number of leaves, the survival rate and seedling emergence, number of bunches per plant and number of fruits per bunch and seed yield of the accessions since seeds and oil yields depend on these parameters (Koutroubas *et al.*, 1999). The purpose of this work was to study the yielding ability, the yield related traits and the oil yield of three castor bean accessions (Motso 1, Motso 2 and Ndoutourou) cultivated in field in two agro ecological savannah zones, the Sudano-Guinea zone and the Sudano-Sahelian zone. The importance and usefulness of this work follows from the fact that the castor bean accession that adapts best in two agro-ecological zones of Northern Cameroon and has a better oil yield will be popularized.

Materials and methods

Description of experimental sites

The field study took place from July 2011 to February 2012 in two agro-ecological zones of Northern Cameroon: the Sudano-guinea zone and the Sudano-sahelian zone. Table 1 shows some agro-pedological characteristics of the studied sites. In the Sudano-guinea zone, the study was carried out at the locality of Bini-Dang in Ngaoundere region situated at 7 ° 24' 671" north latitude, 13° 34' 238" east longitude and altitude 1155.8 m. The vegetation of the cultivated area is herbaceous savanna dominated by *Imperata cylindrica* and *Pennisetum purpureum*, some shrubs such as *Annona senegalensis, Hymenocardia acida* and *Terminalia* spp. The Sudano-guinea climate is characterized by two seasons of equal length; the rainy season runs from mid-March to mid-September and the dry season from mid-September to mid-March. The rainfall is unimodal and ranged from 1200 to 2000 mm, with an average at 1479 mm. The average temperature ranges between 22 °C and 24 °C. In the Sudano-Sahelian zone, the study was conducted in the district of Maroua III in the quarter called "Abattoir" situated at 09° 3' 9" north latitude, 10.32° 13' 4" east longitude and 713 m altitude. The area cultivated is herbaceous savanna dominated by *Imperata cylindrica*. The climate of the Sudano-Sahelian zone is characterized by high temperatures (28 ° C on average per year) with a large irregular rainfall; the duration of the dry season is higher (from november to june) than that of rainy season (from July to October).

Seeds samples

The principal treatments comprised three accessions of castor beans namely Motso 1, Motso 2 and Ndoutourou, all obtained from the SODECOTON of Garoua in Cameroon, a governmental industry interested in the production of castor oil. The seeds were all brown in colour with black lines (figure 1) and distinguishable on the basic of their size. Motso 2 has larger seeds size while Ndoutourou has smaller seeds size and Motso 1 intermediate seeds size.

Experimental design

All wild plants were cut off from the experimental sites. Thereafter each site was plowed to 30 cm depth and ridges of 16.5 m × 8 m were formed. Space between two consecutive ridges was 3 m. Each experimental site used for this work measured 1665 m². The experimental design consisted of three treatments (castor bean accessions) lay out randomly and repeated in three blocks. The same experimental design was adopted in the two study areas. Each unit plot measured 16.5 m×8 m (figure 2).

Seeds sowing

Sowing was done on July 2011 in both experimental sites. The seeds had not undergone any treatment before sowing. Seeds were chosen just based on their phenotypic traits, the best being the seeds with a large thick and not being attacked by weevils. After plowing, castor bean seeds were sown at 4 to 5 cm depth to 1.5 m intervals on the same row and 2 m interval between two consecutive rows on the same unit plot. Each row contained 10 planting holes and 3 seeds were sowed per planting hole. Each experimental unit received three rows and 90 planting holes. The distance between two consecutive unit plots was 2 m.

Determination of seed yield and yield related traits

Two weeks after sowing, seedling emergence rate was evaluated on all samples and thinning was done one month after sowing so as to leave one plant per planting hole. During the vegetative phase, the number of leaves and plant height were measured on 10 targeted plants at regular intervals of 30 days.

The dry biomass and stem diameter of plants were evaluated at flowering on 4 targeted plants at the center of the plot. The survival rate of the plants was estimated at flowering as the ratio of the total number of plants counted with the initial total number of plants. At maturity, the number of bunches per plant, fruits per bunch and seed yields expressed in kg ha^{-1} were assessed. Seeds harvested per treatment were solar dried and stored in dry environment for future evaluation of oil yield.

Determination of oil yields

Dried seeds were assembled according to accession and agro-ecological zone and the lipid extracted with n-hexane in a soxhlet following the IUPAC method (1979). Intermittent hot extraction operated for 8 h after with hexane was removed by evaporation in a rotor vapor set at 40°C and the residue made of oil was dried for 1 h at 60°C. The oil was weighted and expressed as to kg $tons^{-1}$ dry seeds, and the value of the oil content used to determine the oil yield (expressed in kg oil ha^{-1}) by multiplying with the seed yield according to the formula:

Oil yield (kg ha-1) = oil content (kg oil $tons^{-1}$ seeds) x seed yield (tons seeds ha^{-1}).

Means and confidence intervals were determined from triplicate measurements. Data were subjected to variance analysis following by the Duncan multiple range tests when any significant effect was observed. The statistical software "Statgraphics plus" was used for this propose.

Results

Effect of accessions, blocks and agro-ecological zones on the yield and yield related traits

Table 2 resumes the analysis of variances (anova) on the yield and yield related traits of castor bean. The anova table decomposes the variability of each variable into contribution due to various factors. It revealed that all the analyzed variables significantly ($p<0.05$) varied from one accession to another. The most important effect of accession was observed on the number of fruits with a contribution on the variability of more than 70.6% as compared to other factors (block and zone).

As revealed by the analysis of variance component, the less important effect of accession was observed on the number of bunch, leaves and yield with an amount variability contribution of 0%. The effect of agro-ecological zone can also be observed as significant for only height, number of leaves, dry matter, and diameter. The high variability associated to the agro-ecological zone was diameter with an amount contribution of 59.7%, followed by height (40%) and dry matter (29.15%). In most cases the block effect was shown to induce less variability (contribution to variance equal to 0%) even though some significant variations ($p<0.05$) were observed on the height, the number of bunches per plant, the number of leaves and fruits per plant.

Seedling emergence rate

Accession was shown to have significant ($p<0.05$) effect on seedling emergence. Two weeks after sowing, the seedling emergence rates of the different accessions (Motso1, Motso2 and Ndoutourou) were significantly ($p<0.05$) high in the sahelian zone (59.9%, 79.2% and 75.9%) compared to the guinea zone (53.3%, 66.7% and 54.8%, respectively). In addition, Motso 2 exhibited the highest seedling emergence rate while Motso 1 had the lowest value, irrespective of the zone. The observed variation showed the genetic dependence of the seedling emergence rate. Moreover the sandy soil of the sahelian zone seemed to favor the seedling emergence rate thus justifying that the seedling emergence rate depended on the environmental conditions.

Variations in the height of castor plants

The changes in height of castor plants after sowing in the guinea and sahelian zones are shown in figure 3. All the curves showed a slow increase of height at the initial growing stage, followed by an exponential growth and a tendency to equilibrium at the end. From the figure it can be seen that the accessions Motso 1 and Motso 2 exhibited higher height growth while the accession Ndoutourou exhibited lower height growth. In addition the height growth of all castor plant accessions in guinea zone was systematically higher than that in the sahelian zone.

The statistical analysis of the data revealed that the trend in height growth followed a sigmoid curve equation of the following form:

$$Height\ (cm) = \frac{\textbf{maximum height}}{1 + e^{\frac{-(T-\tau)}{Ti}}}$$

were T is the growing time expressed in month, τ is the time to achieve half maximum growth, and Ti is the time needed to initiate growth after sowing. The height growth characteristics of castor plants namely τ, Ti and maximum height for 3 accessions in the two agro-ecological zones are shown in table 3. These characteristics revealed that all the accessions in the guinea zone performed well compared to the sahelian zone. In this respect the height of castor plants in the guinea zone was about 1.5 to 2 fold the height in the sahelian zone. In addition the half maximum height time, τ, did not show significant variation from one zone to another while Ti, the time to initiate growing after sowing was systematically higher in the sahelian zone compared to the guinea zone.

The accessions also exhibited height growth characteristics significantly different ($p<0.05$). In this respect while Motso 1 and Motso 2 possessed the maximum and similar height growths, Ndoutourou exhibited significant ($p<0.05$) lower value, about 1.6 times less than Motso 1 and Motso 2. Similar trends were observed for τ and Ti. In fact while no significant variation was observed between Motso 1 and Motso 2 for both characteristics, Ndoutourou exhibited significant ($p<0.05$) higher values of τ and Ti in comparison with values for Motso 1 and Motso 2. These results suggested a genotypic difference amongst the accession Motso 1 and 2, and Ndoutourou. In addition the growing conditions in the guinea savannah are more favorable to castor bean growth compared to the sahelian savannah. The plant height is an important yield trait, unfortunately the pearson linear correlation analysis with yield revealed a non significant ($r=0.159$; $p=0.183$) linear relationship. Controversially, the change in height has been significantly linear ($r=0.325$, $p=0.005$) correlated to the change in the number of leaves, the most important trait directly associated with fruiting and seed yield.

This observation suggested that the height of castor plant is not a general indicator of seed yield. However within each accession, any factor susceptible to improve the increase in plant height also improved the seed yield as demonstrated by the significant correlation observed between both parameters plant height and seed yields within each accession: $r=0.34$ ($p=0.10$), $r=0.41$ ($p<0.05$) and $r=0.42$ ($p<0.05$) for Motso 1, Motso 2 and Ndoutourou, respectively.

Variations in the number of leaves of castor plants during growing

The changes in the number of leaves during growth of castor plants in the guinea and sahelian agro-ecological zones are presented in figure 4. The curves show that during the 2 first months of growing, plants leaves increased slowly, after this period of time an exponential increase was observed up to an optimum depending to the accession and the agroecological zones. During the four growing period, Motso 1 and Motso 2 in the guinea agro-ecological zone had higher number of leaves compared to others. After this time, Ndoutourou in guinea zone developed more leaves and possesses at the end of the 8 growing period of this study the highest number of leaves. Although Ndoutourou also show important development in leaves in the sahelian zone, the number at the end of the 8 months of growing was still lower than the value of Motso 1 and Motso 2 in the guinea zone. Generally after the optimal growing time, a decrease in the number of leaves was observed. In fact, Motso 1 and Motso 2 achieved their optimum at the 5th month while Ndoutourou achieved its optimum at the 6th month in the sahelian zone and 7th in the guinea zone. Another difference observed on these curves is the number of leaves per plants in each agro-ecological zone. Generally all the accessions in the guinea zone exhibited higher number of leaves compared to those in the sahelian zone. Between all the yield related traits, the number of leaves was found to be the most linear correlated to the seeds yield ($r=0.47$, $p<0.001$). Within each accession, the correlation between the number of leaves and the seed yield was found significant ($r=0.52$, $p=0.009$).

Table 1. Agro-pedological characteristics of the experimental fields.

Agro-pedological characteristics	Zones of studied fields	
	Ngaoundere	Maroua
Color	reddish brown	White
Texture	argillaceous	Sandy
pH	5.64	6.8
Phosphorus (mg/100g DM)	0.04	0.03
Nitrogen (mg/100g DM)	0.16	0.11
Climate	Sudano-Guinea	Sudano-Sahelian
vegetation	Shrub savannah	Herbaceous savannah

Table 2. Summary of the analysis of variance for the effect of accession, agro-ecological zones and blocks on the yield and yield related traits of castor plants.

Yield and yield related traits	Sources of variations	Somme of square	Degree of freedom	Mean square	F-ratio
Height	Accessions	220437	2	110210	63.55
	Blocks	65636.4	2	32812.2	18.92
	Zones	292925	1	292925	168.90
Diameter	Accessions	15.6735	2	7.837	69.56
	Blocks	0.3355	2	0.1668	1.48 (ns)
	Zones	31.8668	1	31.887	282.46
Dry matter	Accessions	8.733	2	4.366	42.63
	Blocks	0.1088	2	0.054	0.53 (ns)
	Zones	6.2965	1	6.297	61.48
Number of bunches	Accessions	117.73	2	58.867	3.51
	Blocks	185.233	2	92.617	5.52
	Zones	0.0222	1	0.022	0.00 ns
Number of leaves	Accessions	6379.23	2	3189.62	10.52
	Blocks	6102.23	2	3051.12	10.06
	Zones	13921.6	1	13921.6	45.90
Number of fruits per bunch	Accessions	31603.0	2	15801.5	140.23
	Blocks	941.033	2	470.517	4.18
	Zones	211.25	1	211.25	1.87 (ns)
Seeds yield	Accessions	8.889	2	4.444	25.32
	Blocks	234589	2	117295	0.67 (ns)
	Zones	437131	1	437131	2.49 (ns)

Table 3. Height growth characteristics of 3 accessions of castor plants in two agro-ecological zones model estimated mean ± standard error; τ is the time to achieved half maximum growth, and Ti the time needed to initiate growth after sowing

accession	Height growth characteristics	Agro-ecological zones	
		Sahelian zone	Guinea zone
Motso 1	Maximum height growth (cm)	105.2±2.54	197.9±1.34
	Ti (month)	0.61±0.092	0.68±0.024
	τ (month)	3.35±0.136	2.95±0.040
Motso 2	Maximum height growth (cm)	107.6±0.94	218.3±1.33
	Ti (month)	0.57±0.030	0.73±0.022
	τ (month)	3.09±0.054	2.98±0.035
Ndoutourou	Maximum height growth (cm)	67.69±2.27	99.6±0.88
	Ti (month)	0.77±0.129	0.66±0.033
	τ (month)	4.079±0.123	3.45±0.045

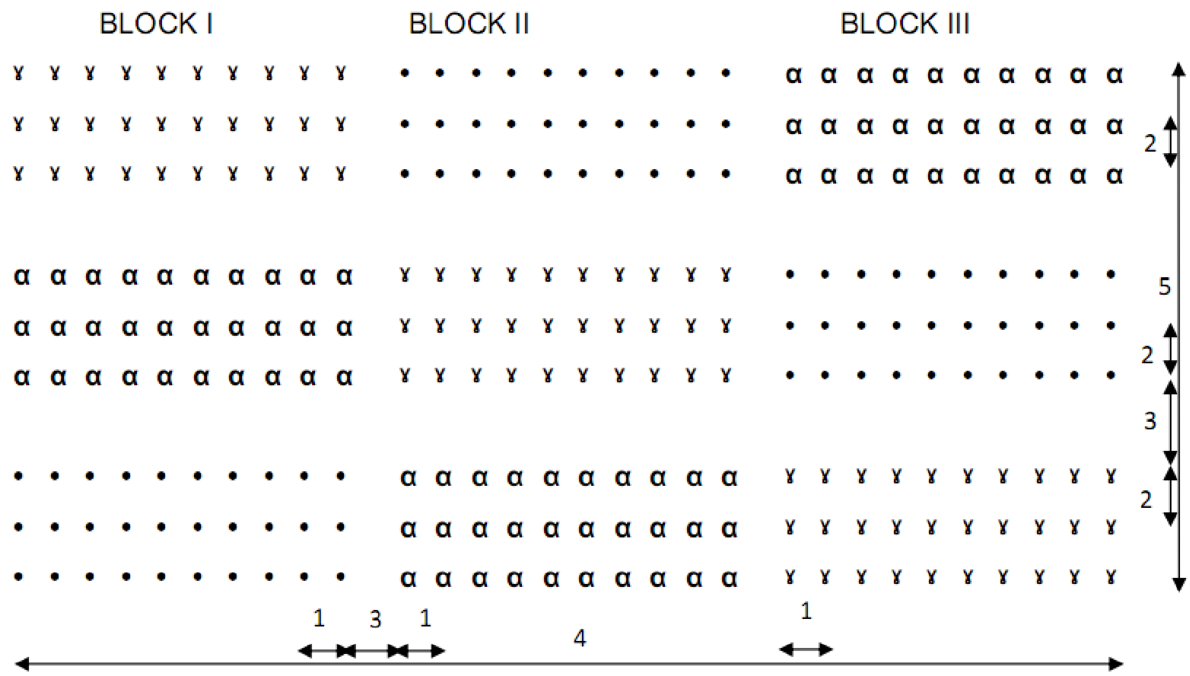
Table 4. Oil yield (t ha^{-1}) depending castor bean accessions and agro-ecological zone.

Castor bean accessions	Sudano-Guinea zone	Sudano-sahelian zone
Motso 1	1.87±0.008	1.47±0.003
Motso 2	2.28 ± 0.006	1.97±0.007
Ndoutourou	4.09±0.004	4.28±0.02

Fig. 1. Seeds of castor bean accessions.

a) Motso 1 b) Motso 2 c) Ndoutourou

Fig. 2. Diagram of experimental design



•: Motso 1 accession; **α:** Motso 2 accession; ᵞ: Ndoutourou accession; 1=1.5m; 2=2m; 3=3m; 4=55.5m; 5=30m

Diameter of stem and dry biomass of plants

The effect of castor bean accession and agro-ecological zone on the diameter of stem and the dry biomass is presented in figures 5 and 6. Irrespective of the zone, the highest values of these parameters were observed for Motso 2 while the smallest values were observed for Ndoutourou accession with a stem diameter of about 2 to 3 fold lower than the others. In addition the stem diameter and the dry biomass were about 2 fold higher in guinean zone compared to sahelian zone. Generally a significant linear correlation was observed between the stem diameter and the dry biomass ($r=0.91$; $p<0.001$), the plant height ($r=0.68$, $p<0.001$), then showing that increase in stem diameter follows the general increase in height and biomass.

Survival rate of castor bean plants at flowering

The survival rate of castor bean plants revealed that irrespective of the zone Ndoutourou possessed the highest percentage while Motso 1 had the lowest percentage. In addition the survival rate was significantly ($p<0.05$) higher in Sudano-guinean zone compared to the Sudano-sahelian zone. The survival rate of castor bean plants of Motso 1, Motso 2 and Ndoutourou accessions were respectively 87.3, 93.6 and 97.3% in Sudano-Guinean zone and 83.0, 90.8 and 93.7% in the Sudano-Sahelian zone.

Number of bunches per plant, number of fruits per bunch and seeds yield of castor bean plants

There is significant difference ($p<0.05$) between the number of bunches per plants, number of fruits per bunch and between seeds yield of different castor bean accessions used for this study (figure 7, 8 and 9). The highest number of bunches per plant was observed for Motso 2 accession (5.6 ± 0.53) while no significant difference was observed between Motso 1 and Ndoutourou which presented a mean number of bunches equaled to 3.90 ± 0.50. In the two agro-ecological zones, the highest number of fruits per bunch was observed for Ndoutourou with a mean value of 39.9±1.37 while the smallest number was observed for Motso 2 with a mean value of 9.6 ± 1.50, and Motso 1 a mean value of 14.6±1.50. These results reflected a negative relationship between the number of bunches and the number of fruits per bunch. In fact a negative linear correlation was observed between both parameters ($r=-0.28$, $p=0.017$). This suggested that within our samples, accession with high number of bunches per plant unit possessed few fruits per bunch, and vice versa. Both characters, high number of bunches per plant unit and high number of fruits per bunch, are interesting however none of our samples did not succeeds in having them. Whatever the case, the total number of fruits per plant is the most important parameter that define the seed yield. Multiplying the number of bunches by the number of fruits per bunch, we observed that while Ndoutourou exhibited a mean value of 156±3 fruit per plants, Motso 1 had a mean value of 57±3 fruits per plant and Motso 54±2 fruits per plant. These results then highlighted the high yield potential of Ndoutourou accession. In this respect we observed generally that Ndoutourou exhibited higher seed yield with a mean value of 8614±611 kg ha^{-1} compared to Motso 1 (mean seed yield of 3450±276 kg ha^{-1}) and Motso 2 (mean seed yield of 4450±260 kg ha^{-1}) which have lower values. These results confirmed the difference observed on the number of fruits which was about 3 fold higher in Ndoutourou compared to Motso 1 and Motso 2.

Oil yield

The variation in the oil yield as a function of the agro-ecological zone and the accession is shown in table 4. Irrespective of the zone, the accession Ndoutourou has the highest oil yield while the accession Motso 1 had the lowest oil yield. The effect of accession however revealed a significant interaction with the agro-ecological zone. In fact we observed that while in motso 1 and motso 2 the oil yield was higher in sudano-guinea zone than in sudano sahelian zone, a reverse effect was observed for the accession Ndoutourou. This variation revealed a significant environmental variation of the oil yield in castor bean.

Discussion

Seedling of castor plant has been demonstrated to emerge between 11 to 26 days varying with the years and soil (Koutroubas *et al.*, 1999). According to Maroyi (2007), germination of castor bean typically ends between 15 and 21 days after sowing (Maroyi, 2007). In the present study the seedling emergence rate determined 14 days after sowing was significantly higher in the sahelian zone than in the guinea zone. This difference suggested that hot temperature and sandy soil that characterize sahelian zone favored seedling emergence of castor. Koutroubas *et al.* (1999) revealed in their study that higher soil temperature at sowing resulted in shorter times of emergence.

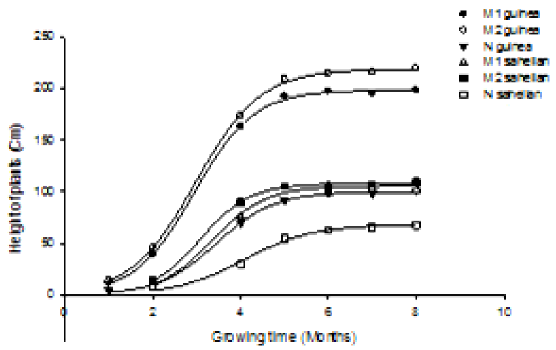


Fig. 3. Variation in the height growth of castor plants after sowing. Each point is mean of 10 replicates; M1, M2 and N are the accessions Motso 1, Motso 2 and Ndoutourou respectively.

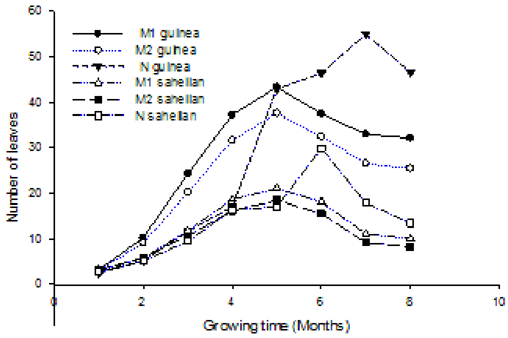


Fig. 4. Variation in the number of leaves of 3 accessions of castor plants after sowing in two agro-ecological zones guinea and sahelian. Each point is mean of 10 replicates; M1, M2 and N are the accessions Motso 1, Motso 2 and Ndoutourou respectively.

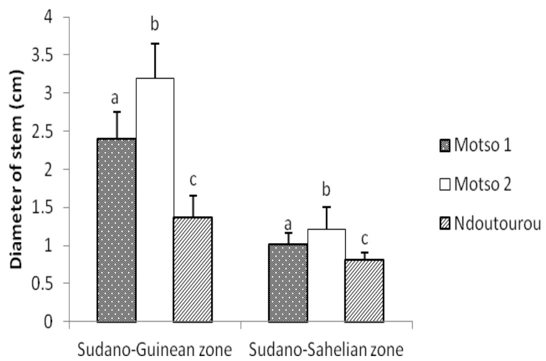


Fig. 5. Diameter of stem at collet depending castor bean accessions agroecological zone. The values of two bands from the same agro-ecological zone affected by the same letter are not significantly different.

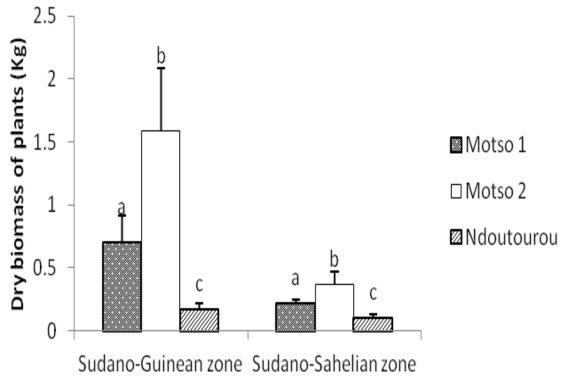


Fig. 6. Dry biomass of castor bean plants according to accession and agroecological zone The values of two bands from the same agro-ecological zone affected by the same letter are not significantly different.

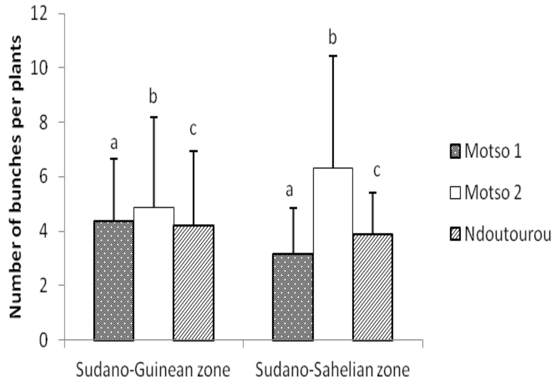


Fig. 7. Number of bunches per plants depending castor bean accessions and agroecological zones. The values of two bands from the same agro-ecological zone affected by the same letter are not significantly different.

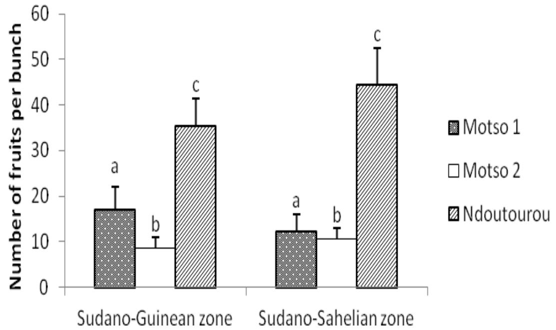


Fig. 8. Number of castor bean fruits per bunch according to accessions and agro-ecological zones. The values of two bands from the same agro-ecological zone affected by the same letter are not significantly different.

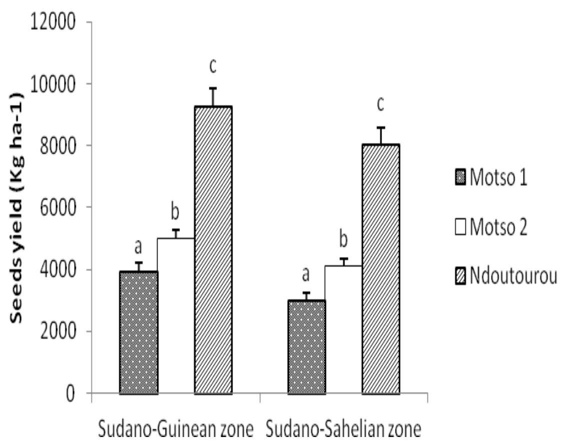


Fig. 9. Seed yield (Kg/ha) depending castor bean accessions and agro-ecological zones. The values of two bands from the same agro-ecological zone affected by the same letter are not significantly different.

Based on this theory, favorable period of sowing in Cameroon is mid-September to mid-March in the guinea zone and November to June in the sahelian zone. Sowing in the present study took place in July when the soil was still hot in the sahelian zone and thus may justify the highest emergence rate observed.

The growth parameters of castor plants varied with the agroecological zone. In the soudano guinea zone, most of the plant height growth parameters were significantly higher compared to that in the soudano sahelian zone. In Ngaoundere the soil organic matter and the rainfall were higher than on the Maroua farm. In addition Ngaoundéré has a microclimate with a high relative humidity and all these conditions favored the vegetative growth of plants. Plant heights, number of leaves, diameter of stem and the seeds yields of castor plants were systematically higher in the guinea zone than in the sahelian zone. Such conditions have been shown in Greece to favor the growth of castor plant. In the present work, a growth difference of 2 to 3 fold for some plants growth parameters such as the height, the number of leaves and the diameter of stem was observed between both agro-ecological zones. In addition the genotype differed in seeds and oil yields and castor plants growth parameters.

The plant height is an important parameter for the harvesting process. In fact tall plant are not easily subjected to harvesting and castor plants with height lower than 2 m are considered easily harvestable (Koutroubas *et al.*, 1999). In this work all the plants height were < 1.1 m in the sahelian zone and <2.1 in the guinea zone. In this respect our castor genotypes are easily harvestable. The height of our castor genotypes were comparable to the range 0.79-2.30 reported for 19 castor genotypes in Greece (Koutroubas *et al.*, 1999). Our castor genotypes can growth more and yield height taller than the actual values. In fact we did not used fertilizer in this work, while recent study revealed a dependence of the castor bean height (69.6 cm to 111.8 cm) with the nitrogen nutrition level (0 to 100 g N, respectively) (Reddy and Matcha, 2010). In the present study the soil nitrogen content was <0.16 mg/100g, very low suggesting poor natural growing conditions and necessity for improvement of soil management for optimum growth. For instance our recent study revealed that the accession Ndoutourou increased its height from 60 to 80 cm when intercropped with common bean, an N-fixing leguminous plant (Tchuenteu *et al.*, 2013). One important contribution to knowledge on this work is the mathematical modeling of castor height with growth time. We found that the height growth followed significantly (r^2>0.99; p<0.001) a sigmoid growth which tends to a maximum height that is computable. More important is the modeling of the effect of other factors such as the nitrogen content as soil amendment on the height growth of castor plant. In this work we found that all the constant of the equation namely the maximum height growth, the time to achieve half maximum growth, τ, and the time needed to initiate growth after sowing, Ti, significantly (p<0.05) varied with the accession and the agroecological zone of plantation. Similar growing behavior of castor height was reported in our recent study (Tchuenteu *et al.*, 2013), but the equation was not applied.

Total number of leaves, and plant height and the distribution of branches are among others the major factors determining the seed and oil yield,

based on their photosynthesis active radiation interception (Reddy and Matcha, 2010). In this respect any factor that affects these parameters will affect the seed yield. The present study revealed a significant ($p<0.05$) correlation between the plant height, the number of leaves, the stem diameter and the seed yield. The extensions of these parameters among others are recognized as basic phenomena of shoot morphogenesis and growth (Reddy and Matcha, 2010). However the change in the number of leaves not only presented an increase at the early stage of growing as the other parameters which increased continuously, but a decrease 5 to 7 months after sowing also followed. The time at which the decrease in the number of leaves appeared varied not only with the castor genotype, but also with the environmental conditions. Ndoutourou has not only the highest number of leaves per plant, but also lose his leaves latter. The period at which Ndoutourou plants started to lose its leaves varied with the agro-ecological zone while the other accessions started losing their leaves at 5 months irrespective of the zone of growing. This result demonstrated a significant interaction between the agro-ecological zone and the accession.

Castor is cultivated for its seeds and oil which yield was shown to vary with many factors including genotype, environment, cultural and harvesting practices (Koutroubas *et al.*, 1999). Compared to the literature, a significant ($p<0.05$) effect of genotype and non significant effect of environment was observed on the seed and oil yields in the present study. We found that Ndoutourou had the highest seed yield while Motso 1 had the lowest seed yield. Although the seed yield was high in the soudano guinea zone compared to the soudano-sahelian zone, no significant variation was observed. Similar trend was observed for the seed yield but the values were systematically higher in the guinea zone compared to the sahelian. Reported seeds yield in literature for commercial castor genotypes were 2.5 to 5.0 $Mg.ha^{-1}$ (Koutroubas *et al.*, 1999) while the reported oil yields were 1.23 to 2.63 Mg ha-1.

Some of our seeds yield values were in this range and varied from 3 to 8 $Mg.ha^{-1}$ with Ndoutourou exhibiting yields particularly high. In addition the oil yield (1.47 to 4.28 Mg ha^{-1}) was in the range reported earlier for commercial genotypes with Ndoutourou out of this range. The average world yield of castor oil seeds has been reported to 1.1 t ha^{-1}, and under favorable conditions this can rich the value of 4-5 $t.ha^{-1}$ (Scholz and Da Silva, 2008). Koutroubas *et al* (1999) reported significant correlation between the oil yield and seed yield, but the trend varied with the year. In fact these authors found during two consecutive years a negative ($r=-0.77$; $p<0.05$) and positive ($r=0.77$; $p<0.01$) correlation between the seeds yield and oil yield. While the positive correlation seemed evident to understand, the negative correlation was explained by the authors to be due to the oil content. This fact seems to be one of the futures of castor plant. In the present study, we found that Ndoutourou had the highest oil content (53.6%) in the sudano-sahelian zone while it possessed the lowest oil content in the sudano-guinea zone (44.4%). In addition Ndoutourou possessed the highest seeds yield in both agroecological zones. Similar cross-variation of oil content with growing zone was observed by Koutroubas *et al.*, (2013), but the ranking of the accession according to the oil yield was almost the same as that of the seed yield in the different growing zone. On a comparative basic, the level of oil content fall within the range reported in literature for commercial genotypes (43-53%) and hence highlighted the high potential of our accession, and particularly Ndoutourou.

In overall the seed and yields obtained for Ndoutourou was high and among the highest reported in literature. As mentioned above the yields were highest for accession Ndoutourou in the soudano guinea zone. This probably resulted in a higher degree of photosynthesis and consequently a greater supply of assimilates compared to other genotypes. As described earlier (Koutroubas *et al.*, 1999), castor is a C3 plant which has a high photosynthesis capacity under high humidity conditions but very sensitive to low humidity.

The climate and soil conditions in the sudano-guinea zone seemed to favor castor growing. In fact the sudano-Guinean climate is more humid; the soil has an argillaceous texture, rich in organic manure and has acid pH while the sudano-sahelian soil has a sandy texture and neutral pH and is poor in organic manure (table 1). According to Weiss (2000) castor plants growth well in a little shade environment where soil is rich in organic manure, well drained and has a neutral pH. In particular Ndoutourou had the highest number of leaves, number of fruit per bunch and consequently the highest oil and seed yields.

Conclusion

Castor plants growth parameters and seeds/oil yields varied between accession and growing zones. Ndoutourou accession has the lowest height, diameter of stem but the highest number of leaves, number of fruit per bunch and consequently the highest seed and oil yield. All the growth parameters were higher in the sudano-guinea zone compared to the sudano-sahelian zone due to its high humidity and soil rich in organic manure. Among the accessions, and the reported data in literature, Ndoutourou has a high potential of castor seed production with an average seed yield of 9000 kg ha-1, and an average oil yield of 4.09 t ha-1. The low value of oil yield in the guinea zone is due to its low oil content which is evaluates to 44.4%. Seeds and oil yields can be improved if soil amendment, cultural and growing conditions are improved. Further research will then investigated the effect of organic and microbial manure on the seeds and oil yield of Ndoutourou castor accession. Particular interest will focus on the changing of height growth parameters following the sigmoid equation.

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