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Original Research Article

Genotype x Environment Interactions for Oil Content in Cotton (*Gossypium hirsutum* L.) Cultivars Grown in Northern Cameroon

Mamoudou Malalha[1], Dolinassou, S.[2], Katoukam, M.[1], Noubissié Tchiagam Jean Baptiste[1*]

[1]Department of Biological Sciences, Faculty of Science, University of Ngaoundéré, P.O. Box 454, Ngaoundéré, Cameroon
[2]Department of Biological Sciences, Faculty of Science, University of Maroua, P.O. Box 814, Maroua, Cameroon

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Abstract: Cotton breeding programs are mainly focus on improving fiber although the oil extracted from cotton seeds is the fifth vegetable oil consumed in the world due to its good quality. The purpose of this study was to evaluate six cultivars of *Gossypium hirsutum* regarding their oil content on four locations in the northern Cameroon during two consecutive seasons, in order to select stable genotypes for high oil content. In each location, the experimental design was a completely randomized block with three replications. The determination of the oil content of the cottonseeds was done by the Soxhlet method. Genotype x environment interaction (GEI) and analysis of stability of the varieties were determined by different methods using GEST 98 package. The variability among genotypes was high across environments for oil content (20.34% in Berem to 26.08% in Kourgui). The top ranked lines for oil were Irma Q302 (26.61%) and Irma A2249 (26.40%). This showed that there is genetic and environmental variability that can be exploited for the selection of genotypes at each site. The broad-sense heritability for oil content varied from 0.79 (Pitoa) to 0.83 (Berem) and expected genetic gain ranged from 14% to 23% with an overall average of 19%. Genotypes, environment and GEI effects were all significant and accounted respectively 35.65%, 43.41% and 20.93% of the total variation. Stability analysis identified high-yielding genotype Irma Q302 as specifically adapted to favourable environments of Kourgui and Pitoa.

Keywords: *Gossypium hirsutum*, oil content, genotype x environment interaction, stability analysis, Northern Cameroon.

INTRODUCTION

Cotton (*Gossypium hirsutum* L., 4n = 52) is the most cultivated fiber plant in the world nowadays, produced in more than 30 countries (Wu *et al*., 2022). Harvesting and ginning cotton crop generates two marketable products: hull that produces fiber and linters, and seed. Cotton is primarily an important fiber crop but also produced many byproducts (Agarwal *et al*., 2003). The kernel (60% of the weight of the seed) composed of 38% oil, of 35% protein, is used for human consumption and animal feeding (Cornu, 2011; Bolek *et al*., 2016). Although accounting for about 60% of biomass of cotton bolls, cottonseed products provide only a secondary revenue stream of cotton crop and mainly from oil fraction (Amer *et al*., 2020). More than 10-15% of cotton grower's income is expected to derive from the valuable byproducts (Sharif *et al*., 2019). Cottonseed oil has several applications in the food, cosmetic and pharmaceutical sectors. The oil extracted from these seeds is the fifth vegetable oil consumed in the world (Gong *et al*., 2022). More recently, the use of cottonseed oil for renewal fuels has also attracted attention as it has a negative carbon profile and could significantly reduce $C0_2$ emission in comparison to fossil fuels (Wu *et al*., 2022). Cottonseed oil is among the most unsaturated edible oils; cholesterol-free, and it is considered as a healthy vegetable oil using to reduce saturated fat intake (Ashokkumar & Ravikesavam, 2011). Cottonseed oil has a mild taste, and it is rich in tocopherols with high level of antioxidant activity (Fok *et al*., 1999). Cotton oil is used in food after removal of gossypol, a highly toxic alkaloid present in all aerial parts except in fibers and seed coat (Eldessouky *et al*., 2021). With 'glandless' varieties without gossypol, cotton might become progressively a food plant (Wu *et al*., 2022). Properly de-oiled cottonseed meal has many uses in food and feed; it can also be mixed with cereal

***Corresponding Author:** Noubissié Tchiagam Jean Baptiste
Department of Biological Sciences, Faculty of Science, University of Ngaoundéré, P.O. Box 454, Ngaoundéré, Cameroon

flours to make bread and cookies (Kohel, 1980). Cotton breeders are making great efforts to change the traditional breeding programs, by switching for programs including improvement in fiber and cottonseed, subsequently; they will maximize return on investments (Eldessouky *et al*., 2021). Various breeding procedures have been employed with different levels of success for improving the quantity and quality of cottonseed oil content (Dani, 1990).

In Cameroon, cotton sector is one of the main providers of national currency and contributes to the improvement of food security (Liba'a & Havard, 2006). Cotton land in Cameroon is located in the northern part of the country which includes the three regions: Adamawa, North and Far-north (Gergely, 2009; Levrat, 2010). The national cotton company, the parastatal SODECOTON has its own cottonseed processing plants making oil and cakes. The cotton sector in Africa, and particularly in Cameroon, is currently facing multiple problems (geographic and climatic challenges, overpopulated and overworked growing area, drop in cotton yields in the various production areas; high production costs due to diseases, biotic and abiotic factors, and insects) (Gergely, 2009). Unfortunately, the random and uncontrolled cultivation of cotton can lead to high expenses and low yields. Current climatic difficulties offer new challenges to which varietal research must continue to face by offering varied ranges of genotypes adapted to the different growing conditions. To avoid these damages, the study of genotype x environment interactions is interesting. The genetic variability for oil content in cotton is widely reported in the literature (Carvalho *et al*., 2017). The effects of environment and genotype interaction on cotton parameters and oil content are well documented (Shafti *et al*., 1992; Laghari *et al*., 2003; Reddy & Satyanarayana, 2004; Campbell & Jones, 2005; Zheljazkov *et al*., 2009; Zenebe & Mohammed, 2010; Alem & Tadesse, 2014; Singh *et al*., 2014; Dolinassou *et al*., 2017). Selection for high oil content does not appear to compromise fiber yield and quality (Eldessouky *et al*., 2021). In the cotton belt in Cameroon, varietal improvement for stability in seed oil content and adaptation to specific environment has not received adequate attention. The major objective of this study was to understand the adaptation of six promising varieties of *Gossypium hirsutum* cultivated on four locations of the northern part of Cameroon during two years by assessing the effects of genotype, environment and their interaction in terms of cottonseed oil content. The aim of the study is to select for this biochemical trait high-potential lines that are not sensitive to climatic variations for wide cultivation across the northern Cameroun areas or to select in each locality promising materials specifically adapted.

MATERIAL AND METHODS

Testing Environments and Genotypes

The trials were conducted in the Northern Cameroon during two seasons (2017 and 2018) at four sites of cotton belt: Berem (7°33'N, 13°55'E) in the Adamawa region, Goudouba (10°57'N, 14°10'E) and Kourgui (10°05'N, 14°06'E) in the far north region, and Pitoa (9°22'N, 13°31'E) in the north region. These test locations present varying climatic and agro-ecological conditions (Table 1).

The biological material consists of six main cotton varieties provided by SODECOTON (Cameroon Cotton Development Company). Irma L484, Irma L457, and Irma Q302 are actually cultivated, while Irma A2249, Irma W2863, and Irma Z2347 are promising genotypes under evaluation. These varieties differ in morphology and characteristics (Table 2).

Table 1: Some environmental characteristics of the experimental sites

Location	Region	Climate	Altitude	Rainfall	TP	Soil type
Berem (Nganha)	Adamawa	Sudano-guinea	911m	1240 mm (April -October)	22°C	Ferralitic
Goudouba (Mora)	Far north	Sudano-sahelian	578m	602 mm (June-September)	21°C	Ferruginous vertisols
Kourgui (Mora)	Far north	Sudano-sahelian	508m	700 mm (June-September)	20°C	Sandy clay
Pitoa (Benoue)	North	Sudano-sahelian	476m	945 mm (June-October)	28°C	Clay loam

TP: annual temperature

Table 2: Origin and characteristics of the six tested genotypes

Variety	Pedigree	Origin	Cultivated Zone	Agronomy	Fiber yield per plant (g)
Irma L484	NTA88-6 x Irma D160	Cameroon (1996)	Far north	Drought tolerant	25.90
Irma L457	ISA784 x Irma B192	Cameroon (1996)	North	High yield	21.22
Irma Q302	IrmaBLPF x IrmaI466	Cameroon (1999)	North and Far north	High yield, fiber quality	27.69
Irma A2249	Q295 x Irma L457	Cameroon	In testing	High yield, vigor	24.40
Irma W2863	Irma BLT x Fuan Zuncho	Cameroon	In testing	High yield, fiber quality	24.72
Irma Z2347	Irma 29 x ISA 319	Cameroon	In testing	High yield, precocity	25.40

Field Experimental Trials

In each location, the experimental design was a completely randomized block design with three replications. Each plot consisted of 18 ridges and each ridge (4.0m length and 2.0m broad) constituted an experimental unit. A ridge consisted of five rows with 10 hills spaced 0.4m apart. Four seeds were sown per hill and thinned to one plant per hill at emergence. Normal cultural practices including weeding, applications of inorganic fertilizers and chemicals were followed throughout the plantings. At maturity, mature bolls were collected on 20 randomly selected plants per replication. After ginning the cottonseeds, samples were acid-delinted, and were oven-dried at about 40°C four 24 hours. Dried seeds were ground in Moulinex model PREP'LINE 850, and the conservation of the samples was done by using hermetically sealed containers in a refrigerator.

Oil Content Estimation

The crude oil was evaluated by continuous extraction in a Soxhlet apparatus using hexane as solvent as described by Kohel (1980). For this purpose, 2g of ground sample were weighed and introduced into a cellulose cone paper previously dried in an oven at 105°C for 1h30 min. The sample and filter paper were weighed and placed in the Soxhlet extractor. The extractor was mounted on a flask containing 200 ml of hexane placed in a heating flask. Once the Soxhlet cooler was installed, the valve was opened and the heater flask was turned on. The fat in the paw was gradually dissolved. The solvent containing the fat returned to the flask in successive spills caused by siphoning into the side elbow. Thus only the solvent could evaporate again, the fat accumulated in the flask. The extraction was carried out for about 10 hours, until the discoloration of the packed samples in the extractor. Once the extraction was completed, the filter paper sample pack was removed and placed in the oven at 105°C for 24 hours and weighed. The total oil content (TL) is calculated by the following formula:

$TL\ (g/100g\ dw) = [(M_1 - M_2)/ (M_1 - M_0)] \times 100$

Where, Mo was the mass of the empty filter paper bag, M_1 was the mass of the full bag containing the test sample before extraction, and M_2 was the mass of the full bag containing the test sample after oil extraction

Statistical and Genetic Analysis

Data of the six lines across the four locations during the two growing seasons were subjected to the simple analysis of variance (ANOVA) using computer program Statgraphics Plus version 3. The genotypic and environmental means were compared were compared using least significant difference (LSD) at 5% level of probability. The heritability in broad-sense (h^2) was assessed using within-population variance (σ_i^2 corresponding to environmental variance) and between-populations variance (σ_I^2 corresponding to total phenotypic variance) as outlined by Lynch and Walsch (1998). Broad-sense heritability is given by the formula:

$h^2 = = (\sigma_I^2 - \sigma_i^2)/ \sigma_I^2$

The expected selection gain (G) was estimated from the value of heritability (h^2) and phenotypic variance (σ_p^2) using the formula proposed by Allard (1960) as:

$G = K \times (\sigma^2{}_p)^{1/2} \times h^2$

Where, K was the standardized selection differential whose value depends on the percentage of selection (K = 1.76 for 10% selection intensity), $\sigma^2{}_p$ was the phenotypic variance, and h^2 was the broad-sense heritability value.

The genetic advance expressed as percentage of mean (G %) was measured by the following formula:

$G\% = (G/M) \times 100$

Where G was the expected gain from selection, and, M was the overall mean of the population.

The repeatability in each location is the Karl Pearson's coefficient of correlation between the two crop seasons. When the repeatability value is significant ($p < 0.05$), the data from the two seasons are summarized.

The analysis on genotype by environment interaction (GEI), and stability analysis were performed using the GEST 98 micro-computer program (Ukai, 2000). The combined analysis of variance across locations was done as proposed by Hardwick and Wood (1972) with genotypes considered as fixed effects. GEI was quantified using pooled analysis of variance, which partitions of the total variance into its component parts namely genotype, environment, GEI, and pooled error.

Different stability models were performed: the Finlay and Wilkinson's (1963) joint regression analysis (*bi)* for the stability and adaptability of the genotypes, the Wricke's (1962) ecovalence (*Wi*), the Shukla's (1972) variance procedure (δi^2), and Huhn's (1990) stability parameter (Si^3). The smallest values of *Wi*, δi^2, and S_3i indicts high stability while high values show instability of the genotypes (Crossa *et al*., 1991) .To graphically explain the GEI and the adaptation of genotypes to environments, the AMM1 (Main additive effects and multiplicative interaction) biplot between the PCA (Principal Component Analysis) scores, and genotypes and environments means was used as highlighted by Okuno (1971), and Crossa *et al.,* (1991).

RESULTS AND DISCUSSION

Variability of Oil Content across Environments

The mean, coefficient of variation, least significant difference and repeatability for oil content for each environment and across environments are presented in Table 3. The analysis of variance, in each locality and across environments revealed significant differences ($p < 0.05$) among genotypes for the cottonseed oil content. The mean oil content of genotypes across environments ranged from 20.84% for Irma Z2347 to 26.61% for Irma Q302 with the grand mean yield of 24.14%. The two top ranked lines were Irma Q302 and Irma A2249. The mean oil content over the four localities varied between 20.34% (Berem) to 26.08% (Kourgui) (Table 3). The coefficient of correlation between the two growing seasons (repeatability) was highly significant ($p<0.01$) and varied from 0.90 to 0.96 depending on locations, suggesting that the differences among years did not affect the cottonseed oil content. Earlier studies have shown the non- significance of genotype x year interaction for oil content in peanut grown in northern Cameroon (Dolinassou *et al*., 2017). Previous cotton researchers also reported significant variability among germplasm for cottonseed oil content (Kohel, 1980; Fok *et al*., 1999 ; Agarwal *et al*., 2003; Lukonge *et al*., 2007; Khan *et al*., 2010; Bolek *et al*., 2016; Eldessouky *et al*., 2021). The availability of genetic variation affects the outcome of a breeding program. It appeared that, in the studied materials, the values cottonseed oil content fell into those the ranges reported by many authors as Singh *et al.,* (2014) in India (range of 19.00 to 24.50%); Carvalho *et al.,* (2017) in Brazil (range of 23.52 to 24.51%) and Sharif *et al.,* (2019) in Pakistan (range of 14 to 25.8%). The results obtained are in disagreement with those of Cornu (2001) who evaluated at 34% the oil content in cottonseed. These contents are lower than those of other oilseeds, as they vary between 47.49% and 61.66% for peanut (Baring *et al*., 2013; Dolinassou *et al*., 2017); from 38-45% for *Linum usitatissimun* (Alem and Tadesse, 2014); and 50% for sesame (Zenebe and Mohammed, 2010). According to Eldessouky *et al.*, (2021), the oil mainly accumulates in the embryo of cottonseed. Some of the incompatible views of past researchers about cottonseed oil content might be due genotypic and environmental variations and also to genotypic ambiance of the varieties used in various environmental conditions. Agarwal *et al.*, (2003) noted that climatic factors such as rainfall, temperature, biotic and abiotic stress, and mineral nutrition as well as the interaction of all these factors with the genetic makeup of a line, affects the oil content and quality of cotton seed. According to Abdul and Ejaz (2005), in peanut, high temperatures and low rainfall induce a decrease in oil content, probably by causing a premature termination of lipogenesis. In sunflower, Zheljazkov *et al*., (2009) highlighted that seed total oil content is negatively influenced by soil mineral nitrogen content. The biochemical processes involved in the biosynthesis of seed oil are relatively well known (Wu *et al*., 2022).

Table 3: Mean cottonseed oil content of the six *Gossypium hirsutum* varieties across four environments of northern Cameroon during two cropping seasons

Genotypes	**Oil content (%) across environnements**				**Genotype mean**
	Berem	Goudouba	Kourgui	Pitoa	
Irma L484	18.73^{c}	25.93^{b}	26.43^{b}	24.23^{c}	23.83±3.53^{b}
Irma L457	22.83^{a}	23.10^{c}	23.03^{c}	23.43^{c}	23.10±0.25^{b}
Irma Q302	21.37^{b}	29.10^{a}	28.60^{a}	27.37^{ab}	26.61±3.56^{a}
Irma A2249	23.53^{a}	27.30^{b}	26.27^{b}	28.50^{a}	26.40±2.11^{a}
Irma W2863	19.47^{c}	21.57^{d}	28.73^{a}	26.50^{b}	24.07±4.29^{b}
Irma Z2347	16.13^{d}	21.03^{d}	23.40^{c}	22.80^{c}	20.84±3.29^{c}
Environment's mean	20.34^{C}	24.67^{B}	26.08^{A}	25.47^{AB}	24.14
CV (%)	13.67	13.21	9.39	9.07	11.33
LSD (5%)	1.47	1.53	2.16	2.00	1.89
Repeatability	0.94**	0.90**	0.92**	0.96**	

CV: Coefficient of variation, LSD: Least significant difference; Means followed by the same letter are not significantly different at 5% level of probability; **: significant at 0.01 probability level

Heritability across Environments

The broad heritability for oil content of genotypes ranged from 0.80 (Pitoa) to 0.83 (Berem) with an average of 0.81 (Table 4). Khan *et al.,* (2010) observed very high heritability (0.87) for oil content in cotton, while Carvalho *et al.,* (2017) recorded low, moderate and elevated values of heritability for trait depending on environments. Mert *et al.,* (2004) noted heritability of cottonseed oil content was moderate (h^2= 0.52) and dominance and additive gene actions play a key role in the heritance. Kohel (1980) also investigated the inheritance of cottonseed oil and noted moderate to high heritability with ranges of 0.42 to 0.66. Dolinassou *et al.,* (2017) found high heritability in oil content, ranging from 0.67 to 0.72 for in peanut. Broad-sense heritability is an estimate of the portion of the total variance that ascribed to genetic causes.

The expected gain of selection from the analysis Allard's (1960) analysis ranged from 14.08% (Pitoa) to 23.10% (Berem) with an overall average of 18.62% for the environments studied (Table 4). Regarding cottonseed oil content, Carvalho *et al.,* (2017) pointed out that the selection based on overall mean is indicated since the character showed high heritability, with 4.58% expected gain. According to Wu *et al.,* (2022), a classic breeding approach through crosses between selected germplasm led to moderate increase of 21-25% of oil content. Heritability expresses the reliability of the phenotypic value as an indicator of genotypic value, so that the higher the heritability, the greater should be the genetic gain with selection. Both additive and non-additive gene actions were reported for oil content in cotton, but non-additive gene action seems to have greater importance (Khan *et al*., 2010).

Table 4: Broad-sense heritability and genetic advance for cottonseed oil content

Parameter	Environments				Average
	Berem	**Goudouba**	**Kourgui**	**Pitoa**	
σ_I^2	7.70	10.69	6.00	5.33	
σ_i^2	1.31	2.03	1.14	1.07	
h²	0.83	0.81	0.81	0.79	0.81
G (k =1.76)	4.7	5.42	4.05	3.54	4.42
G (%)	23.10	21.97	15.53	14.08	18.62

σ_I^2: total phenotypic or inter-varietal variance **;** σ_I^2: environmental or intra-varietal variance ; h² : broad-sense heritability, G : expected genetic advance, G% : expected genetic advance of the genotypes as percent of mean; K: the selection differential in standard units and it was 1.75 at 10% intensity of selection.

Combined Analysis of Variance

The combined analysis of variance using the model of Hardwick and Wood (1972) (Table 5) showed that genotypes, environments and GEI effects were all significant ($p < 0.05$). Cottonseed oil content was mainly affected by environment effects which explained 43.41% of the total variation, while genotypes and the GEI captured respectively 35.65% and 20.93% of the total sum of square. The variations due to environments and genotypes components indicated diversity in environmental conditions and differential behavior of the tested lines. As noted by Carvalho *et al.,* (2017) in Brazil, among the main effects, the effect of environments had the greatest contribution to the variation of oil content. Reddy & Satyanarayana (2004), and Singh *et al.,* (2014) also noticed similar results for cottonseed oil content in India. The pooled analysis of variance also showed that the GEI mean square was significant for oil content and explained 20.93% of the total variation. Campbell *et al.,* (2005) also noted that in cotton, GEI significantly impacted oil content and accounted for 24% of the total variation. Gong *et al.,* (2022) also highlighted the importance of GEI effect for the kernel oil content of cotton in China. This result is contrary to the finding of Singh *et al.,* (2014) which noted that the effect GEI was non-significant for cottonseed oil content. When the interaction is significant, no valid comparison could be made regarding the performance of genotypes over all environments. This is an E>G>I type of interaction. According to Baring *et al.,* (2013) the effects of genotype, environments and GEI were significant for peanut oil content. Zenebe and Mohammed (2010) on the analysis of GxE interactions of sesame oil content showed that the effects of environment, genotype, GEI accounted respectively 16.8%, 30.5% and 4.6% suggesting for this fact a strong involvement of genotype, hence the G>E>I type of interaction. Gong *et al.,* (2022) showed by interaction network analysis that meteorological and geographical factors explained 38% of the total kernel oil cotton variance in cotton, with average daily rainfall contributing the largest positive impact and cumulative rainfall having the largest negative impact on oil content accumulation. The expression of the main components of cottonseed oil content is the result of combination of genotype and ecological environment.

Table 5: Combined analysis of variance for cottonseed oil content of six genotypes across four environments

Source of variation	df	SS	% SS	MS	F-value
Genotype (G)	5	92	35.65	18.40	8.36**
Environment (E)	3	112	43.41	37.33	16.97**
Interaction (GEI)	15	54	20.93	3.60	1.63*
Residual	10	22		2.20	
Total	**23**	**258**	**100**		

df: degree of freedom; SS: Sum of square; % SS: Percent of the sum of square; MS: Mean square; F: Fisher value; *: significant at 0.05 probability level; ** : significant at 0.01 probability level.

Stability and Adaptability for Oil Content

The values of different stability parameters for kernel oil content of each of the six cotton genotypes and ranking are presented in Table 6. The values of *bi* adaptability parameter of Finlay and Wilkinson (1963) ranged from 0.14 (Irma L457) to 1.35 (Irma W2863). According to Finlay and Wilkinson (1963) model of adaptability, high values of regression coefficient ($bi > 1$) indicates that a variety is sensitive to environmental changes and more responsive to rich environments, while low values ($bi < 1$) is an indication that the genotype has greater resistance to environmental changes and may be adopted in poor environments. Varieties Irma Q302, Irma L484, Irma Z2347 and Irma W2863 showed *bi* larger than 1.0 so they are indicated to superior yielding environments (Kourgui and Pitoa).

In contrast, Irma L457 and Irma A2249 had their regression coefficients smaller than 1.0, hence they are considered to be adapted to the unfavorable environment (Berem). None of the tested varieties showed general adaptability because a stable variety is one with above mean yield and regression coefficient of unity (*bi* ≈ 1.0).

Shukla's (1962) variance parameter (σ_i^2) and Wricke's (1972) ecovalence (*Wi*) which is the contribution of a genotype to GEI sum of square, ranged from 0.44 (Irma Z2347) to 8.40 (Irma L457) and 2.69 (Irma Z2347) to 18.61 (Irma L457) (Table 6). The stability variance is a linear combination of the ecovalence, and the difference in magnitude indicated the variation in degree of stability. These results showed that Irma Z2347, Irma L484, Irma A2249 and Irma Q302 had the lowest σ_i^2 and *Wi* values therefore considered as the most stable while Irma L457 and Irma W2863 with greatest values of σ_i^2 and *Wi* showed high instability.

According to the stability analysis using Huhn (1990) non-parametric method, Irma Z2347, Irma L484 and Irma Q302 were the most stable varieties for oil content (Si^3 varied from 0.13 to 1.0), while Irma A2249, Irma W2863 and Irma L457 appeared as the most unstable genotypes (Table 6). This non-parametric stability analysis is less sensitive to error than the parametric analysis and the addition or deletion of one or a few observations is not likely to cause much variation in the evaluation (Crossa *et al*., 1991).

In general, data obtained on stability showed that none of the tested varieties could be considered as completely stable. The ideal genotype should have the highest mean performance and be absolutely stable (σ_i^2, *Wi* and Si^3 = 0). Stability analysis identified low-yielding genotype Irma 2347 as the most stable while other cultivars were specifically adapted to favourable environments of Kourgui and Pitoa. The procedures used in this study are not contradictory in selection for oil content in the tested environments of northern Cameroon and could consequently be jointly used to explore genotype x environment interaction.

Table 6: Genotypic stability and adaptability of the six genotypes for oil content

Code - genotype	Mean oil (%)	*bi*	*Wi*	σ_i^2	S_i^3
1-Irma L484	23.83 (4)	1.27 (5)	4.69 (2)	1.44 (2)	0.73 (2)
2-Irma L457	23.10 (5)	0.14 (1)	18.61 (6)	8.40 (6)	2.06 (4)
3-Irma Q302	26.61 (1)	1.28 (4)	7.61 (4)	2.95 (4)	1.00 (3)
4-Irma A2249	26.40 (2)	0.72 (2)	6.69 (3)	2.44 (3)	3.00 (6)
5-Irma W2863	24.07 (3)	1.35 (6)	14.03 (5)	6.11(5)	2.69 (5)
6-Irma Z2347	20.84 (6)	1.26 (3)	2.69 (1)	0.44 (1)	0.13 (1)

bi: Finlay and Wilkinson 's (1963) regression coefficient; *Wi* : Wricke 's (1962) ecovalence; σ_i^2: Shukla's (1972) stability variance; S_i^3: Huhn's (1990) stability parameter; Number in parenthesis denote ranking of variety for each parameter.

Biplot analysis for oil content

The additive main effects and multiplicative interaction analysis (AMMI) model, which combines the standard analysis of variance with principal component analysis (PCA), is fully informative for both the main effects as well as the multiplicative effects, for clearly understanding the genotype by environment interaction (Okuno, 1971; Crossa *et al.*, 1991). The AMMI biplot analysis provides a graphical representation to summarize information on main effect and interaction of both genotypes and environments (Figure 1). In AMMI1 biplot, the PCA was represented in the y-axis while the genotypes and environments means were represented on the x-axis. By plotting the genotypes and environments in the same graph, their association can be clearly seen. Environments Kourgui and Pitoa, with PCA score greater than zero are classified as favorable environments while Berem and Goudouba with negative PCA values appeared as poor environments. Genotypes Irma A2249 and Irma L484, with PCA score greater than zero are high- yielding genotypes while Irma W2863 and Irma Z2347 with negative PCA values are classified as low-yielding genotypes. Genotypes Irma A2249, Irma Q302 and Irma W2847 and environments Kourgui, Pitoa and Goudouba located on the right side of the perpendicular line have higher oil content comparing to varieties Irma Z2347, Irma L457 and Irma L484, and Berem location situated on the left side. Whatever the direction is, the greater the PCA scores, the more specifically adapted these genotypes were to certain environments. With regard to PCA scores, genotypes Irma Q303, Irma Z2347 and Irma L484 with lowest PCA scores near zero have little interaction effects and were considered as stable across environments. In contrast, genotypes Irma L457, and Irma 2863 with highest PCA scores were the most divergent across tested environments.

Genotypes and environments with PCA scores of the same sign produce positive interaction effects, whereas combination of opposite signs shows negative interaction (Crossa *et al*., 1991). The genotypes Irma Z2347 and Irma L484 interacted positively with the unfavorable site of Berem. The varieties Irma A2249 and Irma L484 interacted positively with favourable environments of Kourgui and Pitoa. High-yielding genotypes Irma Q302 was specifically adapted to Goudouba, Pitoa and Kourgui sites. The major concern of a breeder is to develop stable genotypes that give consistent performance across environments. Hence, Irma Q302 could be recommended in programs of improving cottonseed oil content in North and Far North regions of Cameroon. Ashokkumar and Ravikesavan (2011), Fathi *et al.*, (2018) showed the effectiveness of biplot analysis to study the stability and adaptation analysis of cotton genotypes. Campbell and Jones (2005) also used AMMI analyses in South Carolina to quantify and classify target environments and genotypes for fiber yield.

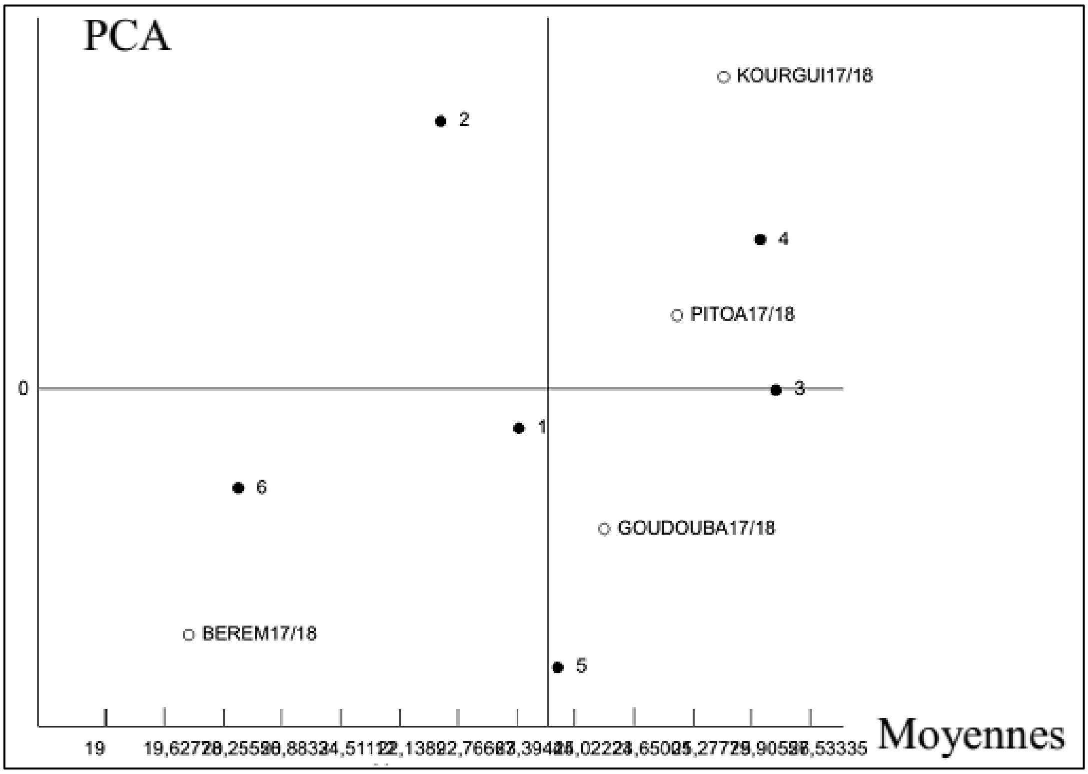

Figure 1: AMMI1 biplot analysis of principal component axis (PCA) against mean oil content of six cotton genotypes and four environments.

Irma L484 (1), Irma L457 (2), Irma Q302 (3), Irma A2249 (4), Irma W2863 (5), Irma Z2347 (6)

CONCLUSION

In the development and release of cotton varieties for cultivation in northern Cameroon, analysis of GEI is necessary to determine their stability and adaptability across locations. The results of this study showed in each environment significant variability for cottonseed oil content among six promising genotypes with Irma Q302 as the best variety regarding oil content. The character showed high heritability (0.79 to 0.83) with 14.08% to 23.10% expected gain from selecting 10% of lines. The combined analysis of variance indicated that environmental effect, genetic factors and GEI significantly affect the variability in oil content. The sites of Kourgui and Pitoa were considered as favorable locations while Berem was unfavorable for oil content. Irma A2249 and Irma Q302 appeared as the most stable across environment. In cottonseed oil content breeding program, not only the differences in varieties, but also the environment effects and GEI should be considered. The results of this study could be used by breeding programs in combination with other conventional and molecular approaches to develop cotton varieties with high oil content in northern Cameroon.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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