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Short-season cotton (*Gossypium hirsutum*) may be a suitable response to late planting in sub-Saharan regions

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ABSTRACT

In Cameroon, seed cotton yields have not increased over the last 20 years because of the shortening of the rainy season and the worsening socioeconomic context. Farmers consequently often delay planting their crops. The main objective of this study was to investigate whether local indeterminate long-season cottons, grown at the recommended density, were more consistent with the farmers' current constraints than determinate short-season cultivars from Latin America that could be sown more densely. We carried out a 3-year three-location survey in northern Cameroon, which included two planting dates (recommended and delayed) and two planting densities (recommended and high). We show that these three factors acted independently. Late planting had a highly negative impact on most traits at both plant and plot scale by delaying flowering, reducing seed cotton yield and fibre quality. Dense sowing mainly had an impact on individual plant traits by reducing boll retention and elongating main-stem internodes. Local cultivars have already evolved favourably (enhanced earliness, yield performance, harvest index, ginning out-turn, and fibre maturity) and could be improved further by crossing with highly determinate cottons. However, such a strategy requires further investigation to ensure that a more determinate growth pattern would not have a negative impact on the adaptive response of the traditional cotton plant to other adverse conditions.

1. Introduction

Because cotton (*Gossypium hirsutum* L.) is the main cash crop in most of the sub-humid region of West Africa, improved cultivars and cropping systems are needed to encourage economic development. Cotton adaptation and productivity in sub-Saharan Africa is an important issue for African cotton producing countries, particularly in the current context of global climate change and unfavourable regional socioeconomic conditions (Pichot et al., 2006). Cotton faces the same difficulties as other crops grown in the area (InterAcademy Council, 2004; FAO, 2006; Lane and Jarvis, 2007).

Cotton has a particular growth pattern. During part of its cycle, vegetative growth occurs concurrently with the development of fruits or 'bolls'. This results in competition for the allocation of photosynthates to benefit fruiting and vegetative growth, with a higher priority of the former over the latter. When the demand for assimilates of growing bolls balance or exceed the carbohydrates supply at the plant scale, the vegetative growth will temporarily stops until the end of boll ripening. This phenomenon can be referred to as "physiological cut-out", defined by Oosterhuis et al. (2008), which is to be distinguished from another form of cut-out that can also occur in adverse weather conditions, the "premature cut-out". Cut-out enhances the versatility of cotton (Oosterhuis and Jernstedt, 1999). When boll development is stalled by stress, the plant switches to channelling photosynthates in favour of vegetative development. New bolls may then develop to replace the ones that have been shed. The cut-out is more or less pronounced depending on the cultivars, i.e., the determinism of the plant growth.

In French-speaking Africa, the 'indeterminate' type widely prevails (Sekloka, 2006). This type features high growth vigour, abundant flowering, high physiological shedding, and gradual boll formation. The cut-out is not clearly defined because at this point, the first bolls have mostly already ripened and the vegetative phase may begin again. An indeterminate growth pattern enables cotton plants to respond appropriately to adverse conditions (pest infestation and irregular rainfall). This is of interest for farmers who grow cotton in extensive rainfed cropping systems, which are common throughout Africa (Crétenet, 2006). On the other hand, the 'determinate' short-season type features early flowering, grouped fruiting, lower physiological shedding, as well as clearly defined cut-out, which may last several weeks. This ideotype is common in mechanized cropping systems in the Americas, for instance.

Like in all French-speaking Africa, seed cotton yields in Cameroon increased regularly until the mid-1980s, peaking at around 1200 kg ha^{-1} (Deveze and Halley des Fontaines, 2005) with

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Table 1
Experimental design at three test sites representative of the cotton-growing area in Cameroon (2003, 2004, 2005).

Site	Djalingo		Makébi		Kodek	
Department	Bénoué		Mayo-Kani		Diamaré	
Province	Nord		Extrême-Nord		Extrême-Nord	
Site closest city	Garoua		Kaélé		Maroua	
Latitude	9°18′N		10°06′N		10°35′N	
Longitude	13°24′E		14°27′E		14°19′E	
Annual rainfall (mm)						
2003	971 mm		912 mm		836 mm	
2004	885 mm		628 mm		543 mm	
2005	708 mm		734 mm		695 mm	
Date of first and last rain > 1 mm						
Year	First	Last	First	Last	First	Last
2003	02 June	23 October	02 June	23 October	03 June	13 October
2004	01 June	24 October	03 June	19 October	01 June	23 September
2005	05 June	23 October	04 May	19 October	01 July	05 October
Plant density						
Recommanded	62 500 (0.8 m × 0.4 m)		100 000 (0.8 m × 0.25 m)		100 000 (0.8 m × 0.25 m)	
High density	167 000 (0.6 m × 0.2 m)		167 000 (0.6 m × 0.2 m)		167 000 (0.6 m × 0.2 m)	
Planting date						
Year	Early	Late	Early	Late	Early	Late
2003	19 June	14 July	07 June	14 July	14 June	08 July
2004	08 June	14 July	08 June	15 July	09 June	13 July
2005	13 June	07 July	10 June	07 July	08 June	06 July
Preplanting cultivation	2003: no tillage; plots were seeded in drilled holes 2004: planting after animal or tractor drawn tillage 2005: planting after animal or tractor drawn tillage					
Thinning	Two plants per hole at the 3- or 4-true leafs stage for all sites					
Organic fertilization before planting	None		5 tons ha^{-1} manure		None	
Chemical fertilization after thinning	Early planting: 200 kg ha^{-1} 15–20–15 Late planting: 100 kg ha^{-1} 15–20–15 45 days after planting: 50 kg ha^{-1} urea		Early planting: 200 kg ha^{-1} 22–10–15 Late planting: 100 kg ha^{-1} 22–10–15 45 days after planting: None		Early planting: 200 kg ha^{-1} 22–10–15 Late planting: 100 kg ha^{-1} 22–10–15 45 days after planting: None	
Pest and weed management	Maximum weed control for all sites Weekly pesticide treatments for all sites					

recent cultivars producing 30–45% more than older cultivars as estimated by Lançon et al. (1990). However, in the last 20 years yields have levelled off, which could be explained by climatic and biotic factors, especially the shortening of the rainy season and the development of pest resistance to pesticides. Deveze and Halley des Fontaines (2005) also identified unfavourable socioeconomic factors, including the drop in the purchase price of cotton, and farmers' land-use strategies (as farmers are not encouraged to sustainably improve the land because of the absence of land property rights), and the lack of training and extension for young farmers and new farmers. As a result, increasing numbers of farmers are adopting cropping practices that are unsuitable for cotton: reducing fertilizer, cultivating infertile plots, and planting late.

This prompted us to address the question of the mismatch between current recommendations and real cropping constraints, which include a wide range of yield potentials and cropping practices, including late planting. Sekloka et al. (2008) proposed using short-season cultivars with low vegetative growth adapted to both late planting and high plant density.

In order to validate Sekloka's proposal under the conditions that prevail in Cameroon, we conducted a 3-year study at three sites in northern Cameroon representative of the Cameroonian cotton-growing area. The objective was to evaluate the potential of short-season cottons, (1) in comparison with currently used local cultivars, (2) with recommended planting and late planting, as well as (3) with recommended spacing and high plant density. We considered most traits of interest to breeders (including fibre quality) to better account for the high compensatory capacity of the cotton plant.

2. Materials and methods

2.1. Experimental design

The trials were carried out over a 3-year period in northern Cameroon at three test sites representative of the Cameroonian cotton-growing area. The rain distribution in this tropical region is typically mono-modal with rainfall lasting for 4–5 months from May–June to September–October, with local differences between sites due to either their latitude or altitude. Rainfall data (Table 1) conform to the classification of Bella-Medjo (2008): annual precipitation of 970–1430 mm at Djalingo in the southern area and

Table 2
Characteristics of the six cotton cultivars studied.

Cultivar	Release	Origin	Cross	Cycle	Flowering	Morphology	Other traits
IRMA BLT-PF	1981	Cameroon	U563-19*(Pan 3492*IRCO 5028)	Indeterminate	Late	High vegetative growth. Pyramidal habit typical of African cultivars selected for early and low plant density	Good fibre length and strength, low ginning out-turn
IRMA D742	2000	Cameroon	IRMA 772*IRMA 2319	Indeterminate	Medium	Intermediate vegetative growth Typical pyramidal habit	Good ginning out-turn
IRMA J129	New elite line	Cameroon	F9-5 × F37-6 and reciprocal cross	Medium	Early	Low vegetative growth Typical pyramidal habit	Good ginning out-turn
S188	–	Nicaragua	(DP 16*Acala 1517 Br)*Gumbo Okra	Indeterminate	Medium	Quite high vegetative growth. Pyramidal habit similar to local African cultivars	Okra type leaf
Guazuncho2	–	Argentina	Guazuncho*SP 8535	Determinate	Very early	Low vegetative growth	Low technological performance
CCA347	–	Bolivia	SP 2510 * DP 41	Determinate	Very early	Low vegetative growth	Low technological performance

Source: D Dessauw and B Hau (personal communication).

750–930 mm at Kodek and Makébi in the northern area. During our study period, rainfall also lasted slightly longer at Djalingo than at Kodek and Makébi.

The elementary plots measured 48 m^2 (10 m × 4.8 m) and were arranged in a split-plot (2003 and 2004) or completely randomized block (2005) design with three replicates. The experiment compared 24 treatments, which were combinations of six cultivars, two planting dates, and two plant densities, resulting in 72 elementary plots per trial (Table 1). In the split-plot design, the date-density combination (henceforth referred as ‘field practice’) was the main plot factor and cultivar was the sub-plot factor.

The planting date actually included two dates: recommended planting date in June and delayed planting date in July. The plant density also included two densities: recommended density with 62 500 or 100 000 plants ha^{-1} depending on the cotton-growing area and high density with 167 000 plants ha^{-1}. Cultivars, planting dates and plant densities were chosen to be as contrasted and realistic as possible. Field practices were in compliance with local cropping guidelines (fertilization, date of each field operation), except for a substantial pest control programme that was implemented to eliminate the effect of pest pressure—a factor that was not analysed in the present study.

The varietal factor consisted of six cultivars, including three Latin American and three African cultivars (Table 2). The short-season cultivars were also early flowering (CCA347, Guazuncho 2 and IRMA J129). Hereafter, we use the term ‘early’ for these cultivars, in contrast with IRMA BLT-PF, a long-season, late flowering cultivar. IRMA D742 and S188 are medium-season, medium-flowering cultivars.

Observations continued throughout the cotton crop cycle (Table 3). The field observations involved monitoring either all plants in the central rows of each plot (i.e. plot traits), or samples of 10 plants (i.e. plant traits).

The central lines of each plot were harvested separately from the lateral lines (i.e. 4 lines for low density or 6 lines for high density). Only the seed cotton from the central lines was weighed and ginned using a 10-saw gin (Continental Eagle Corporation). After ginning, seeds and fibre were weighed. The matter eliminated by the mote-board was also weighed, and because the seed cotton was carefully hand harvested, this was mainly composed of motes. The fibre was sampled and sent to the CIRAD Cotton Technology Laboratory (Montpellier, France) to be analysed on an HVI 900 B line (Uster Technologies) and a Fiber Maturity Tester III (Shirley Developments Ltd.).

2.2. Statistical analysis

All statistical analyses were performed using SAS software (SAS Institute Inc. 2004. SAS OnlineDoc® 9.1.3. Cary, NC: SAS Institute Inc.).

2.2.1. Analysis of variance based on observed variables

To test the different sources of variation among plots, we used the MIXED procedure and the following model:

$$Y_{bijk} = \mu + G_i + P_k + (GP)_{ik} + (SY)_j + B(SYP)_{bjk} + (SYG)_{ij} + (SYP)_{jk} + (GPSY)_{ijk} + E_{bijk},$$

where

Y_{bijk} = phenotypic value of cultivar i, located in block b, within site–year combination j, under field practice k,
μ = overall mean,
G_i = fixed effect of cultivar i ($i \in \{1, 2, \ldots, 6\}$),
P_k = fixed effect of field practice k ($k \in \{1, 2, 3, 4\}$), which is a combination of a planting date and a plant density,
$(GP)_{ik}$ = fixed effect of the cultivar–field practice interaction for class ik,
$(SY)_j$ = random effect of site–year combination j ($j \in \{1, 2, 3, 4, 5, 6\}$),
$B(SYP)_{bjk}$ = random effect of block b within site–year combination j ($b \in \{1, 2, 3\}$),
$(GSY)_{ij}$ = random effect of cultivar–site–year interaction for combination ij,
$(SYP)_{jk}$ = random effect of site–year–field practice interaction for combination jk,
$(GPSY)_{ijk}$ = random effect of cultivar–field practice–site–year interaction for combination ijk,
E_{bijk} = unexplained random residual.

Cultivar and field practice, as well as their interaction, were set as fixed factors because we wanted to draw conclusions only about these cultivars and field practices. The field practice (P_k) was the main plot factor and was tested using the (SYP) interaction as the denominator term. This model did not allow us to test either date or density effects directly. However, both could be tested using the contrast method (see below). The cultivar (G_i) was the sub-plot factor and was tested using the cultivar–site–year interaction (GSY) as the denominator term. The cultivar–field practice interaction (GP)

Table 3
Variables studied at three stages: field, ginning mill, and fiber technology.

Type of monitoring	Type of variable	Symbol	Unit	Variable
Field	Phenological	D1F	Days	Days from emergence to first flower. The day of first flower is the day when 50% of plants in the central lines of the plot have opened their first flower
		NN1FB[a]	–	Node number of the first sympodia branch counted from the cotyledonary node 0. This variable is highly heritable; it is an indicator of the flowering onset and is closely correlated with yield earliness (Ray and Richmond, 1966)
		NB[a]		Number of nodes until insertion of the lowest fruiting branch bearing a boll. This variable, which was introduced by Buxton et al. (1977), can be used to estimate shedding of the first position on the first fruiting branches (SH)
	Morphological	NVB[a]	–	Number of monopodia branches
		NFB[a]	–	Number of sympodia branches
		VIL[a]	cm	Mean length of internodes bearing monopodia
		FIL[a]	cm	Mean length of internodes bearing sympodia
	Yield and components	B5S[a]	–	Number of bolls on the first five sympodia
		SH[a]	–	Shedding of the first position on the first sympodia, which is the difference between NB and NN1FB: SH = NB – NN1FB
		YLD	kg/ha	Seed cotton yield
		PB	kg	Weight of postharvest above-ground biomass
		HI	%	Harvest index = 100 × YLD/(YLD + PB)
		SI	g	Seed index: non-delinted 100 seed weight determined by weighing 100 seeds twice
Ginning mill	Ginning	GOT	%	Ginning out-turn
		SDP	%	Seed percentage
		MOP	%	Mote percentage, indicator of fibre maturity. Mote mainly contains immature ovules whose fibres cannot be separated by the ginning process
Fibre technology	Length	ML	mm	Mean length
		UHML	mm	Upper half mean length
		UI	%	Uniformity index
	Strength	T0	g/tex	Strength
	Elongation	E1	%	Elongation
	Micronaire index	IM	–	Micronaire (commercial criterion that depends on the standard fineness and maturity of the fibre)
	Maturity	PM	%	Percentage of mature fibres (which indicates the fibre filling and dye fixing capacity)
	Fineness	Hs	mtex	Fineness
	Reflectance	Rd	%	Whiteness (or percentage of light reflected by cotton fibres)
	Yellowness	+b	–	Yellowness (indicates the extent of cotton yellowness)

[a] Individual plant traits.

was tested using the (*GPSY*) term as the denominator. If the *GP* term was significant, the cultivar effect was tested again using the interaction mean square as the denominator in the *F* ratio. The site–year interaction (*SY*) was considered to be random because the trials represented only a sample of a wide range of environmental conditions that may be encountered by farmers. The same procedure was applied to site–year–cultivar and site–year–field practice interactions (i.e. *GSY* and *SYP*, respectively). The unexplained residual was used to test these three effects. The option "ddfm = kr" in the Model statement enabled SAS to take into account the proper error term for the calculations. Although random effects are beyond the scope of this article, they were included in the ANOVA model to minimize the error term and enhance the power of the comparison tests.

The multiple-comparison *t*-tests were computed using the LSMEANS statement with the DIFF option.

2.2.2. Breakdown of effects using the contrast method

We performed the contrast analysis using the CONTRAST statement of the MIXED procedure to break down field practices into their elementary terms, i.e. planting date and plant density. Let Y_j, be the observed coordinate of field practice *j* on one axis, the contrasts due to the planting date and the plant density are then defined as follows:

- For the planting date: $C_{date} = (1/2)[Y_{\text{LP\&LD}} + Y_{\text{LP\&HD}}] - (1/2)[Y_{\text{EP\&LD}} + Y_{\text{EP\&HD}}]$
- For the plant density: $C_{density} = (1/2)[Y_{\text{EP\&HD}} + Y_{\text{LP\&HD}}] - (1/2)[Y_{\text{EP\&LD}} + Y_{\text{LP\&LD}}]$

The terms EP and LP stand for early planting and late planting. LD and HD stand for low density and high density. These contrasts were tested using an *F*-statistic.

In the same way, the genetic differences could be broken down into a contrast that accounted for the divergence between the two groups of plant materials:

$$C_{divergence} = (1/3)[Y_{\text{BLT-PF}} + Y_{\text{D742}} + Y_{\text{J129}}] - (1/3)[Y_{\text{S188}} + Y_{\text{Guazuncho 2}} + Y_{\text{CCA347}}]$$

2.2.3. Canonical discriminant analysis based on means of trial treatments

In this analysis, to reduce the volume of data and in order to not eliminate information from plots with one or more missing data, we averaged plot data for the three replications using the MEANS procedure. Thus, the 24 treatments (6 cultivars × 2 planting dates × 2 plant densities) were represented by nine values each (3 sites × 3 years) instead of 27. Canonical discriminant analysis (CDA) was performed using the CANDISC procedure. This multivariate method transformed the 24 observed traits into a few relevant linear combinations or axes that best separated the treatments and that would reflect underlying biological functions. The

Table 4
Sources of variation within 6 cotton cultivars evaluated at 2 planting dates and 2 plant densities in 9 trials in North Cameroon. .

	D1F	NN1FB	NVB	NFB	VIL	FIL	B5S	SH	YLD	HI	SI	GOT
AIC[a]	3144	1110	631	2402	1259	1767	1850	1448	8895	3925	1097	2151
Trial mean	57.6	4.89	0.76	12.2	2.99	5.91	4.65	1.82	1328	48.1	7.78	41.7
Random effects[b]												
SY	107.50 *	0.505 *	0.071 *	4.620 *	0.326 *	1.023 *	0.306 NS	0.103 NS	365,781.5 *	12.32 *	0.691 *	1.009 *
SY × P	23.87 ***	0.100 **	0.024 **	1.106 **	0.176 **	0.362 **	0.315 **	0.166 **	59,917.3 **	4.68 *	0.070 **	0.418 **
Block(SY × P)	1.35 ***	0.016 *	0.000 NS	0.572 ***	0.092 ***	0.271 ***	0.067 *	0.057 **	38,694.7 ***	5.54 ***	0.049 ***	0.147 **
SY × Cultivar	0.74 *	0.045 **	0.009 *	0.099 *	0.012 NS	0.016 NS	0.085 *	0.001 NS	6,265.9 *	2.57 *	0.036 **	0.234 **
SY × P × Cultivar	1.45 **	0.014 NS	0.000 NS	0.000 NS	0.012 NS	0.000 NS	0.125 **	0.000 NS	3,252.2 NS	3.53 *	0.005 NS	0.137 *
Residual	6.19 ***	0.227 ***	0.123 ***	1.860 ***	0.283 ***	0.668 ***	0.744 ***	0.446 ***	66,119.2 ***	21.49 ***	0.217 ***	1.222 ***
Fixed effects												
Practice	NS	*	NS	*	NS	NS	***	NS	***	***	***	**
Cultivar	***	***	***	***	NS	***	***	***	***	***	***	***
Practice × Cultivar	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	*	NS
Conditional cultivar effect within field practice[c]												
EP & HD									NS		***	
EP & LD									***		***	
LP & HD									*		***	
LP & LD									NS		***	

	SDP	MOP	ML	UHML	UI	T0	E1	MI	PM	Hs	Rd	+b
AIC[a]	2329	1701	1529	1441	1724	2275	−37	340	3921	4814	1975	830
Trial mean	55.9	2.16	23.6	28.6	82.5	31.1	5.31	3.35	71.4	183	78.5	9.48
Random effects[b]												
SY	1.868 *	0.459 *	0.205 NS	0.026 NS	1.787 *	0.533 NS	0.030 *	0.065 *	23.92 *	56.22 *	0.411 NS	1.583 *
SY × P	0.814 **	0.144 *	0.229 **	0.236 **	0.120 *	0.236 NS	0.016 **	0.017 *	6.04 *	24.48 *	0.978 **	0.040 *
Block(SY × P)	0.259 **	0.113 **	0.110 ***	0.085 ***	0.111 **	0.346 ***	0.008 ***	0.012 **	6.63 ***	27.74 ***	0.192 ***	0.041 ***
SY × Cultivar	0.396 ***	0.049 *	0.026 NS	0.024 NS	0.035 NS	0.099 NS	0.003 *	0.007 *	2.09 *	4.91 NS	0.072 *	0.025 **
SY × P × Cultivar	0.095 NS	0.025 NS	0.078 **	0.082 **	0.042 NS	0.287 **	0.006 **	0.006 NS	3.67 **	26.51 ***	0.000 NS	0.015 *
Residual	1.600 ***	0.643 ***	0.413 ***	0.355 ***	0.632 ***	1.455 ***	0.031 ***	0.064 ***	21.77 ***	92.22 ***	0.949 ***	0.126 ***
Fixed effects												
Practice	NS	***	**	**	*	NS	**	***	***	***	NS	***
Cultivar	***	***	***	***	***	***	***	***	***	***	***	***
Practice × Cultivar	NS	NS	NS	NS	NS	NS	NS	*	*	NS	*	NS
Conditional cultivar effect within field practice[c]												
EP & HD								***	***		***	
EP & LD								*	***		***	
LP & HD								***	***		***	
LP & LD								***	***		***	

NS; Not significant.
* Significance level: $P < 0.05$.
** Significance level: $P < 0.01$.
*** Significance level: $P < 0.001$.
[a] AIC = Akaike's information criterion.
[b] Random effects of the variation: SY = Site × Year, SY × P = Site × Year × Field practice, Block(SY × P) = Block within Site × Year × Field practice, SY × Cultivar = Site × Year × Cultivar, SY × P × Cultivar = Site × Year × Field practice × Cultivar.
[c] Field practices: EP = early planting, LP = late planting, LD = low density (recommended), HD = high density.

Table 5
Mean performance and contrast tests of field practices evaluated in 9 trials in North Cameroon.

	D1F	NN1FB	NVB	NFB	VIL	FIL	B5S	SH	YLD	HI	SI	GOT
Field practice												
EP&HD	56.7	4.72 b	0.82	12.3 a	3.23 a	6.14	4.48 b	2.03 a	1853 a	50.2 a	8.07 a	42.2 a
EP&LD	55.7	4.65 b	0.82	13.0 a	3.08 ab	5.91	5.66 a	1.85 ab	1647 a	52.1 a	8.08 a	42.1 ab
LP&HD	58.8	5.10 a	0.61	11.2 b	2.69 b	5.97	3.58 c	1.89 ab	967 b	43.3 c	7.43 b	41.4 bc
LP&LD	59.1	5.07 a	0.75	12.0 ab	2.93 ab	5.59	4.87 b	1.49 b	845 b	46.5 b	7.52 b	41.0 c
C_{date} contrast	2.7 NS	0.40**	−0.14*	−1.1*	−0.34*	−0.25 NS	−0.85***	−0.25 NS	−844***	−6.2***	−0.60***	−1.0***
$C_{density}$ contrast	0.4 NS	0.05 NS	−0.07 NS	−0.7 NS	−0.05 NS	0.31 NS	−1.24***	0.29 NS	164 NS	−2.6*	−0.05 NS	0.3 NS

	SDP	MOP	ML	UHML	UI	T0	E1	IM	PM	Hs	Rd	+b
Field practice												
EP&HD	56.1	1.51 b	23.9 a	28.9 a	82.7 a	30.6	5.43 a	3.48 a	74.4 a	178 b	78.3	9.02 b
EP&LD	55.7	1.77 b	23.9 a	28.9 a	82.7 a	30.9	5.42 a	3.54 a	75.6 a	175 b	78.3	8.96 b
LP&HD	55.6	2.54 a	23.2 b	28.2 b	82.2 b	31.3	5.20 b	3.18 b	67.5 b	189 a	78.6	9.95 a
LP&LD	55.8	2.81 a	23.2 b	28.2 b	82.2 b	31.5	5.19 b	3.18 b	68.0 b	188 a	78.7	9.96 a
C_{date} contrast	−0.2 NS	1.04***	−0.7***	−0.7***	−0.5**	0.6*	−0.23***	−0.33***	−7.27***	12***	0.4 NS	0.97***
$C_{density}$ contrast	0.1 NS	−0.27 NS	0.0 NS	0.0 NS	0.0 NS	−0.3 NS	0.01 NS	−0.03 NS	−0.89 NS	2 NS	−0.1 NS	0.03 NS

NS: Not significant.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.
[a]Within each column, class means with same letters are not significantly different.
[b]Field practices: EP = early planting, LP = late planting, LD = low density (recommended), HD = high density.

method maximized interclass variation on successive orthogonal axes and reduced variation due to the other sources (sites, blocks within sites, years, uncontrolled errors) to the unit variance, for all treatments and traits. All traits thus contributed to defining the axes in the same way. We used the following parameters:

- The eigenvalue or expressed variance associated with the axes, as an absolute value and as a percentage;
- Interclass correlations between observed traits and axes calculated on the basis of the class means;
- Coordinates of the classes on each axis.

2.2.4. Analysis of variance and contrast analysis of canonical variables

The class means of canonical discriminant variables were then considered as new variables with normal distribution and analysed using a fixed ANOVA model:

$$Y_{ij} = \mu + G_i + P_j + E_{ij},$$

where

Y_{ij} = phenotypic value of cultivar i in field practice j,
μ = overall mean,

Table 6
Mean performance and contrast tests of local and introduced cotton cultivars evaluated in 9 trials in North Cameroon.

Group	Cultivar	D1F	NN1FB	NVB	NFB	VIL	FIL	B5S	SH	YLD	HI	SI	GOT
Local	BLT-PF	58.6 b	5.51 a	0.96 a	12.8 a	3.03	6.66 a	4.13 de	2.09 a	1323 b	42.4 c	8.47 a	39.9 d
	D742	59.1 a	4.99 b	0.67 cd	12.2 bc	3.02	6.37 b	3.94 e	1.99 a	1295 b	43.6 c	7.65 c	42.6 b
	J129	56.2 c	4.80 bc	0.65 cd	11.9 cd	2.96	5.37 d	4.65 bc	1.76 b	1224 b	47.8 b	8.03 b	43.5 a
Introduced	S188	58.6 a	5.02 b	0.79 bc	11.9 cd	3.05	5.86 c	4.36 cd	1.76 b	1331 b	49.4 b	7.93 b	40.8 c
	Guazuncho	55.9 c	4.42 d	0.62 d	11.4 e	3.05	5.74 c	5.02 b	1.66 b	1491 a	52.7 a	7.31 d	42.6 b
	CCA347	57.2 c	4.57 cd	0.81 b	12.5 ab	2.78	5.43 d	5.78 a	1.65 b	1304 b	52.4 a	7.25 d	40.8 c
$C_{divergence}$		−0.7***	−0.43***	−0.02 NS	−0.4*	−0.04 NS	−0.46***	0.81***	−0.26***	95**	6.9***	−0.55***	−0.6**

Group	Cultivar	SDP	MOP	ML	UHML	UI	T0	E1	IM	PM	Hs	Rd	+b
Local	BLT-PF	58.2 a	1.65 d	25.0 a	30.0 a	83.2 b	33.5 a	5.53 b	3.34 b	73.6 bc	172 d	79.2 a	9.40 b
	D742	54.6 c	2.41 a	24.4 b	29.2 b	83.6 a	32.2 b	5.67 a	3.40 b	74.9 b	170 de	78.4 b	9.55 b
	J129	53.8 d	2.38 ab	23.7 c	28.4 c	83.3 ab	32.0 b	5.43 c	3.51 a	77.2 a	166 e	78.4 b	9.00 c
Introduced	S188	56.8 b	2.07 bc	23.2 d	28.3 c	81.9 c	30.1 c	5.08 d	3.35 b	71.7 c	181 c	78.9 a	9.47 b
	Guazuncho	54.5 cd	2.46 a	22.6 e	27.7 d	81.3 d	29.1 d	5.05 d	3.22 c	66.2 d	199 b	78.5 b	9.39 b
	CCA347	57.0 b	1.97 c	22.5 e	27.6 d	81.6 d	29.5 d	5.08 d	3.23 c	64.8 d	207 a	77.5 c	10.0 a
$C_{divergence}$		0.6**	0.02 NS	−1.6***	−1.3***	−1.8***	−3.0***	−0.48***	−0.15***	−7.68***	26***	−0.4**	0.31***

NS: Not significant.
* Significance level: $P < 0.05$.
** Significance level: $P < 0.01$.
*** Significance level: $P < 0.001$.
[a]Within each column, class means with same letters are not significantly different.

Table 7
Eigenvalues associated with the first five axes in a discriminant factor analysis of variety–date–density combinations.

	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalue	8.14	6.54	2.14	1.66	1.22
Eigenvalue in %	37.8	30.4	10.0	7.7	5.7
Significance level	***	***	***	***	**

** Significance level: $P < 0.01$.
*** Significance level: $P < 0.001$.

G_i = fixed effect of cultivar i ($i \in \{1, 2, \ldots, 6\}$),
P_k = fixed effect of field practice k ($k \in \{1, 2, 3, 4\}$),
E_{ik} = cultivar × field practice interaction considered as residual.

Means were compared using the Ryan–Einot–Gabriel–Welsch multiple range test.

3. Results

3.1. Variation in the traits depended for the most part on main random and fixed factors

Most random effects were significant sources of variation (Table 4). However, when compared with the residual component, their relative contribution varied considerably, depending on both sources and traits. The site–year (SY) component contributed the most variably and most importantly: 14.7 times the residual component for D1F, 11.5 for +b, 5.3 for YLD, but only 0.1 times the residual component for UHML and 0.2 for SH. The site–year–field practice component came in second place: the ratio was 0.2–3.3 times the residual component. The site–year–cultivar component contributed only up to 0.2 times the residual component.

In the same way, fixed effects contributed differently to the variation. The cultivar effect was highly or very highly significant for all traits except vegetative internode length (VIL). The field practice effect was significant for 16 traits out of 24. Their interaction was significant only for 5 traits (YLD, SI, IM, PM, Rd). For these particular traits, we tested the cultivar effect for each field practice by using the SLICE option of the LSMEANS statement. Cultivar differences remained significant whatever the field practice, except seed cotton yield (YLD).

3.2. Early planting and short cycle were most advantageous

Both the multiple-comparison and contrast tests showed that planting date had an impact on up to 19 traits out of 24 (Table 5). The recommended early planting was favourable for most traits: lower insertion level of the first sympodium, higher number of sympodia branches, more favourable yield components (B5S, HI, SI, GOT), higher seed cotton yield, and higher fibre quality (except T0 and Rd). Late planting resulted in unfavourable traits including higher insertion level of the first sympodium, lower seed size and delayed fibre maturity.

Plant density had a significant impact on two traits: high density resulted in lower boll retention and a lower harvest index. High density also resulted in a higher shedding rate and longer fruiting internodes on the main-stem, but these differences were not statistically significant.

The local cultivars differed from the introduced cultivars in many traits (Table 6). The local material featured a longer cycle (D1F, NN1FB), higher vegetative growth (FIL), superior fibre quality (ML, UHML, UI, T0, E1, IM, PM, Hs) but inferior yield components (SH, HI) while the introduced material featured a shorter cycle, lower vegetative growth, superior yield components and inferior fibre quality. In particular, the fibres produced by CCA347 and Guazuncho 2 were too immature. However, the multiple-comparison tests showed that the local cultivars have already evolved favourably since the latest cultivar to be released, IRMA J129, was significantly earlier (lower values for both D1F and NN1FB), had a higher harvest index, ginning out-turn, and higher

Table 8
Interclass correlations between observed traits and the axes of canonical discriminant analysis.

Type	Variable	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Phenological	D1F	0.48*	−0.70***			
	NN1FB	0.75***	−0.45*			
Morphological	NVB			0.81***		0.44*
	NFB		0.48*	0.57**		0.53**
	VIL		0.74***			
	FIL	0.45*		0.67***		−0.42*
Yield	B5S	−0.63**				0.66***
	SH		0.45*	0.48*		−0.45*
	YLD		0.85***			
	HI	−0.83***	0.46*			
	SI	0.46*	0.59**	0.46*		
Ginning out-turn	GOT		0.63**	−0.69***		
Seed percentage	SDP			0.89***		
Mote percentage	MOP		−0.61**	−0.69***		
Length	ML	0.74***	0.44*	0.49*		
	UHML	0.66***	0.40*	0.60**		
	UI	0.83***	0.46*			
Strength	T0	0.93***				
Elongation	E1	0.71***	0.56**			
Micronaire index	IM		0.91***			
Maturity	PM	0.54**	0.80***			
Fineness	Hs	−0.77***	−0.59**			
Color	Rd	0.54**			−0.66***	
	+b		−0.94***			

* Significance level: $P < 0.05$.
** Significance level: $P < 0.01$.
*** Significance level: $P < 0.001$.

Table 9
Class means of synthetic variables obtained from 9 trials to evaluate 6 cotton cultivars at 2 planting dates and 2 plant densities in North Cameroon.

Field practice	Cultivar	Axis 1	Axis 2	Axis 3	Axis5
Class means					
EP&HD	BLT-PF	1.99	1.87	2.95	−0.23
	D742	1.73	2.93	0.34	−1.77
	J129	1.27	3.73	−1.23	0.13
	S188	−1.22	2.04	0.90	−0.67
	Guazuncho2	−3.59	2.17	−0.19	−1.03
	CCA347	−3.99	0.41	1.13	−0.37
EP&LD	BLT-PF	1.81	1.15	2.90	1.12
	D742	1.76	3.51	0.21	−0.15
	J129	1.46	3.69	−1.70	1.63
	S188	−1.49	1.56	0.15	0.67
	Guazuncho2	−3.63	2.41	−0.96	−0.07
	CCA347	−4.02	0.88	0.46	1.54
LP&HD	BLT-PF	3.45	−2.85	1.71	−0.87
	D742	3.61	−1.58	−1.09	−1.85
	J129	2.73	−1.00	−2.23	−0.38
	S188	0.04	−2.33	−0.04	−0.65
	Guazuncho2	−2.30	−1.91	−0.96	−1.63
	CCA347	−2.96	−3.57	0.85	−0.33
LP&LD	BLT-PF	3.07	−2.57	1.11	1.41
	D742	3.65	−1.46	−0.20	0.25
	J129	2.86	−0.66	−2.53	1.51
	S188	−0.34	−2.68	0.01	0.72
	Guazuncho2	−2.88	−1.86	−1.54	−0.38
	CCA347	−2.99	−3.89	−0.02	1.43
ANOVA					
Model fit	Root MSE	0.230	0.273	0.370	0.250
	R^2	0.995	0.912	0.955	0.964
F test	ITK	612.28***	61.09***	56.64***	30.36***
	Cultivar	66.77***	517.91***	12.00***	85.09***
Field practice					
Class means	EP&HD	−0.64 b	2.19 a	0.65 a	−0.66 b
	EP&LD	−0.69 b	2.20 a	0.18 ab	0.79 a
	LP&HD	0.76 a	−2.21 b	−0.30 bc	−0.95 b
	LP&LD	0.56 a	−2.18 b	−0.53 c	0.82 a
Planting date contrast		1.32***	−4.39***	−0.83***	−0.13 NS
Plant density contrast		0.12 NS	−0.02 NS	0.35*	−1.61***
Cultivar					
Class means	BLT-PF	2.58 a	−0.60 d	2.17 a	0.35 ab
	D742	2.69 a	0.85 b	−0.19 c	−0.88 c
	J129	2.08 b	1.44 a	−1.92 e	0.72 a
	S188	−0.75 c	−0.35 d	0.25 bc	0.02 b
	Guazuncho2	−3.10 d	0.20 c	−0.91 c	−0.78 c
	CCA347	−3.49 d	−1.54 e	0.60 b	0.56 a
Divergence contrast		−4.90***	−1.13***	−0.04 NS	−0.13 NS

NS: Not significant.
** Significance level: $P < 0.01$.
* Significance level: $P < 0.05$.
*** Significance level: $P < 0.001$.
[b] Field practices: EP = early planting, LP = late planting, LD = low density (recommended), HD = high density.
[a] Within each column, class means with same letters are not significantly different.

fibre maturity than IRMA BLT-PF, which was released at the beginning of the 1980s.

3.3. The structure of correlations showed four main functions

Canonical discriminant analysis enabled us to organize the 24 observed traits on five main axes. These axes significantly distinguished the 24 classes (cultivar–field practice combinations) and represented up to 91.5% of the total inertia (Table 7). All observed traits were correlated with one or more of the main axes (Table 8).

Axis 1 was found to be significantly correlated with six agronomic traits out of 14 and eight technological traits out of 10. Most correlations were positive: the ones with the flowering lateness indicators (D1F, NN1FB), seed size (SI) and fibre quality traits (ML, UHML, UI, T0, E1, PM, Hs, Rd). Only two correlations were negative: the number of bolls near the plant base (B5S) and harvest index (HI). This axis was not linked with yield. Axis 1 associated vegetative function with fibre quality on one hand (positive values) and reproductive function with flowering earliness on the other (negative values).

Axis 2 was significantly correlated with 10 agronomic traits and eight technological traits. It was positively correlated with flowering earliness (D1F, NN1BF), vegetative growth (NFB, VIL), seed cotton yield (RDTCG), ginning out-turn (GOT), seed size (SI), shedding of the first positions (SH) and fibre quality (ML, UHML, UI, E1, IM, PM, Hs, +b). It was negatively correlated with the percentage of motes (MOP). Axis 2 accounted for the reproductive function and fibre quality (positive values).

Axis 3 was positively correlated with growth parameters (NVB, NFB and FIL), seed size and percentage (SI, SDP), shedding (SH) and fibre length (ML, UHML). It was negatively correlated with fibre and mote percentages (GOT, MOP). Axis 3 accounted for vegetative vigour, seed filling and fibre elongation (positive values).

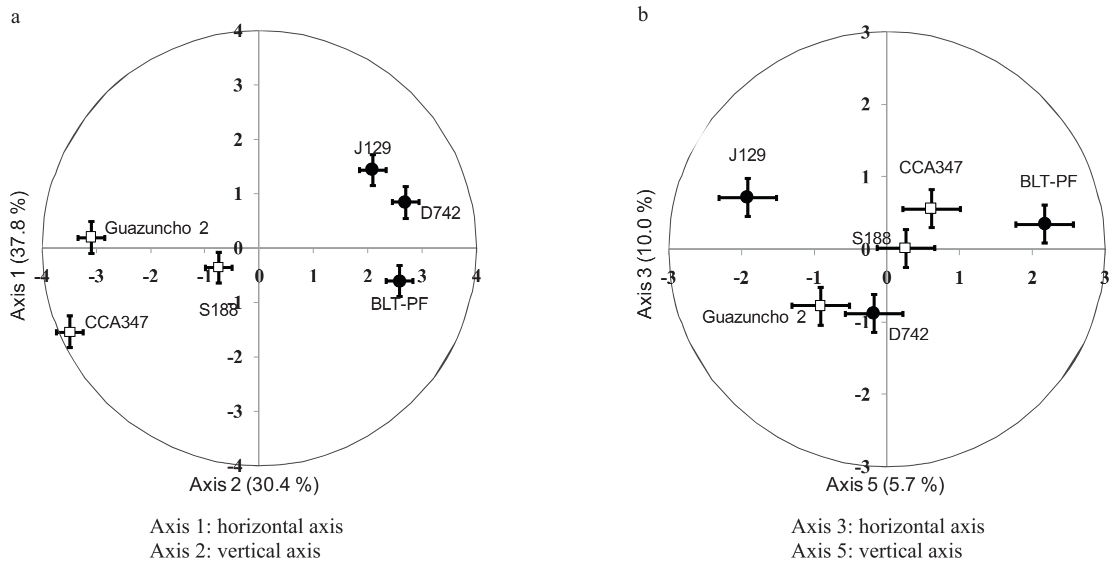

Fig. 1. Coordinates of centroids associated with cotton cultivars and corresponding confidence intervals. (a) Space defined by the intersection of axes 1 and 2 (67.2% of total inertia). (b) Space defined by the intersection of axes 3 and 5 (15.1% of total inertia).

Axis 4 was correlated with a single variable, reflectance (Rd), which was a secondary trait in our study.

Axis 5 was correlated with only five agronomic traits. This axis was positively correlated with the number of vegetative and fruiting branches as well as with the number of bolls near the plant base (NVB, NFB, B5S) and negatively correlated with the mean length of the upper main-stem internodes and shedding on the lower sympodia (FIL, SH). Thus axis 5 accounted for within-plant competition between vegetative and reproductive functions.

In the following, only axes 1, 2, 3 and 5, which represented about 84% of the total eigenvalues, are considered.

3.4. Impact of cultivar and field practice on synthetic variables

The 24 class means of synthetic variables (Table 9) were analysed using a two-factor fixed model. The coefficient of determination was very close to unity, which means that main factors were responsible for the majority of class variation and the interaction was negligible. Hence, the levels of each factor could be compared independently.

3.4.1. Genetic variability was important and structured

All axes significantly distinguished between cultivars (Table 9, Fig. 1). Between-group divergence was the main source of variation among cultivars: the divergence contrast was particularly high on the two first axes. Genetic variation came secondarily from within the Latin American cultivars, since these cultivars differed significantly among themselves on the first and second axes. The local cultivars were very homogenous on the first axis but more variable on the second axis and beyond.

The local group was homogenous on the first axis because the material was selected in the same local conditions. It featured higher vegetative growth, a longer cycle, and higher quality fibre than the introduced cultivars, which came from three different

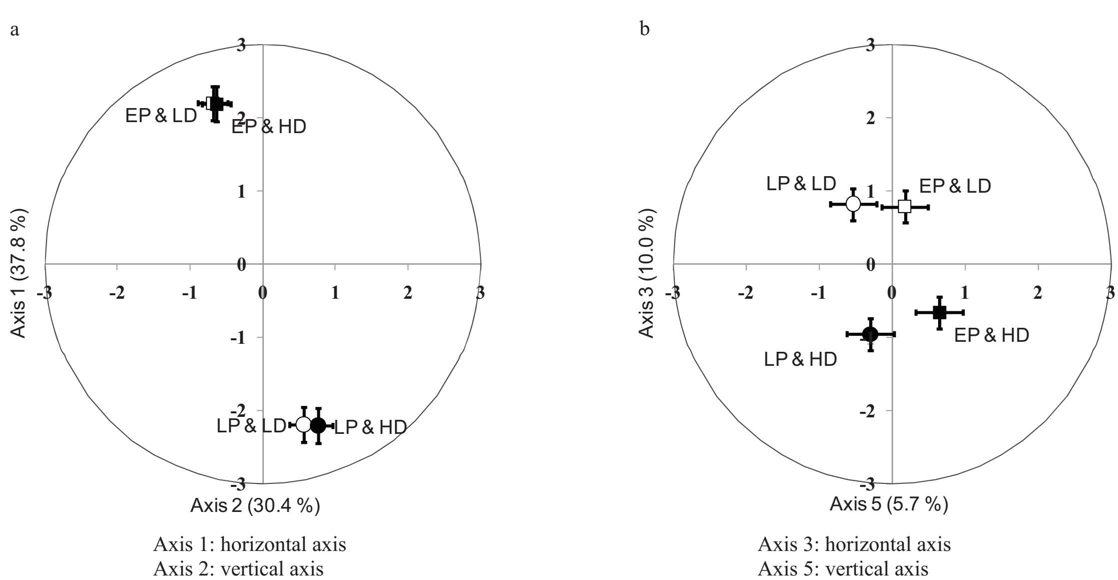

Fig. 2. Coordinates of centroids associated with field practices: early planting (EP), late planting (LP), low plant density (LD), high plant density (HD) and corresponding confidence intervals. (a) Space defined by the intersection of axes 1 and 2 (67.2% of total inertia). (b) Space defined by the intersection of axes 3 and 5 (15.1% of total inertia).

sources. When compared with each other on axes 2 and 3, the local cultivars clearly evolved from a long cycle, high vegetative growth, high shedding, low ginning out-turn, large seeds, long and less mature fibres (as represented by IRMA BLT-PF), towards a shorter cycle, lower vegetative growth, higher boll retention, harvest index and ginning out-turn, smaller seeds, more mature, finer, less yellow, and shorter fibres (as represented by IRMA J129). Moreover, the respective positions of IRMA J129 and IRMA D742 on axis 5 were explained by two traits: better boll retention and shorter fruiting internodes for IRMA J129 and lower boll retention and longer fruiting internodes for IRMA D742 (Table 6).

3.4.2. Planting date had a high impact on all traits

Because most traits were highly influenced by planting date (Table 5), this factor also significantly affected the three first axes (Table 9, Fig. 2). Thus, early planting (June) led to low insertion level of the first sympodia, vigorous vegetative growth, high seed cotton yield and high yield components (HI, GOT, SI), low mote content, and high fibre quality (greater length, uniformity, elongation, maturity, fineness, and low level of yellowness). Late planting led to high insertion level of the first sympodia, low vegetative growth, low yield and yield components, low seed and fibre filling, low maturity level and high level of yellowness. Planting date did not significantly affect flowering date, because the flowering date of the early-planted plots was delayed by slow germination, as the first rains were often insufficient or late. Some early-planted plots were re-sown once or twice, with 1 week between each re-sowing, while late-planted plots had a fast and high germination rate, so that very few of them needed re-sowing. On the other hand, the insertion level of the first sympodia was more reliable because only first-sown plants were considered.

3.4.3. Plant density had an impact on fewer traits than planting date but on more traits than in the univariate analysis

Plant density had an impact on axes 3 and 5, which were significantly correlated with 11 traits out of 24. The plant density contrast on axis 3 was $C_{density} = 0.35^{*}$. However, the difference between densities was not significant when each planting date was considered separately (Table 9). On the other hand, the contrast was very highly significant on axis 5 ($C_{density} = -1.61^{***}$) and the difference between densities at same planting date was also significant. The cotton plants sown in tight rows produced fewer vegetative and fruiting branches than those planted with standard spacing. Tightly planted cotton plants also lost more growing bolls on the lower fruiting branches, and had longer fruiting internodes.

4. Discussion

The question we addressed concerned primarily the mismatch between current recommendations and the real cropping constraints faced by farmers (infertile soil, short rainy season, delayed planting). The impacts of the environment, cultivar, planting date and plant density and their interactions are discussed below.

4.1. Variable impacts of environmental conditions on observed traits

The relative contribution of the site–year component to variation was particularly high for flowering date (D1F) and to a lesser extent, for seed cotton yield (YLD). This fact could partially be linked to the variable germination ratio and re-sowing. Low germination was observed with the early planting date because of the late arrival of rains. As a consequence, sowing could be repeated up to three times, which delayed flowering, decreased the length of the cycle and affected the seed cotton yield. However, the second phenological trait (NN1FB) was less dependent on early conditions, as the trait was evaluated on 10 plants (chosen among those of the first sowing) instead of the whole plot.

4.2. Different impacts of planting date and plant density on traits

Planting date had far more impact on traits than plant density. The overriding effect of planting date over yield related to plant density was described by Munk (2001) in a study that compared five planting dates over a 2-month period and four plant densities ranging from 25 000 to 150 000 plants ha^{-1}. Sekloka (2006) also reported the overriding effect of planting date in the case of a 1-month difference in planting dates and with plant densities ranging from 42 000 to 167 000 plants ha^{-1}.

Plant density had a low impact primarily because the ratios between the two densities we used were low (2.67 at Djalingo and 1.67 at Kodek and Makebi) compared with the range found in the literature: 1.5 (Hawkins and Peacock, 1970) to 16 (Fowler and Ray, 1977). But we deliberately limited high density planting to 167 000 plants ha^{-1} since this is an acceptable peak density for manual cropping. Sekloka (2006) and Sekloka et al. (2007) used the same density in Benin for similar reasons. The low impact of plant density could also be linked to the development pattern of the cotton plant, which is typical of plants with indeterminate growth (Oosterhuis and Jernstedt, 1999). This pattern includes a high capacity for flower initiation and high boll shedding, such that only a small proportion of flower buds that develop actually reach the mature boll stage: 30% according to Guinn (1982) and only 21% according to Crozat et al. (1999). Oosterhuis and Stewart (2004) stated that shedding is a natural way for a cotton plant to adjust its fruit load to the nutrient resources of the environment, so that the total or useful biomass remains stable at the plot scale.

4.3. Planting date and plant density had independent impacts on traits

Planting dates and plant densities were distinguished on quite different axes, suggesting that they acted independently on different sets of traits (with only axis 3 distinguishing both planting dates and plant densities). The lack of date-density interaction was reported by Galadima et al. (2003) for traits such as ginning out-turn, micronaire index and fibre strength. However, an interaction may be observed when a broader range of densities is considered. Thus, Galanopoulou-Sendouka et al. (1980) studied densities ranging from 100 000 to 400 000 plants ha^{-1}, and found an interaction with cycle length, flowering onset, mean maturation date and maturation rate. Dong et al. (2006), compared densities ranging from 300 000 to 750 000 plants ha^{-1}, and found a significant interaction with ginning out-turn and with the number of bolls per surface unit. In both studies, the most suitable field practices combined early planting with low plant density and late planting with high plant density.

4.4. Dense sowing enhanced plant competition and reallocation of resources at the plant scale

Univariate ANOVA and multivariate CDA highlighted the effect of plant density differently. In the univariate approach, plant density had a significant impact on boll retention and harvest index only. The contrast method and multiple-comparison test failed to detect significant differences for vegetative traits (NVB, NFB, VIL, FIL), possibly because of the high environmental effect on these individual field traits. On the other hand, the multivariate approach influenced axes 3 and 5, suggesting that plant density had an impact on more traits (11 out of 24 correlated with one of the two axes or with both). In particular, five individual field traits were significantly correlated with axis 5, three of which were vegetative (NVB, NFB, FIL) and two were reproductive (B5S, SH). The multivariate approach thus revealed compensation or competition between vegetative and reproductive functions better than the univariate approach. These results are in agreement with those of previously published studies (Benedict and Kohel, 1975; Oosterhuis and Stewart, 2004; Heitholt, 1997; Sadras, 1995; Jones et al., 1996; Bednarz and Roberts, 2001; Sekloka, 2006). For example, Sekloka (2006) stated that the architectural and phenological traits of individual cotton plants were more sensitive to plant density than to planting date.

4.5. *Local material has evolved favourably and could be further improved*

Local cultivars were classified in chronological order of their release on axes 2 and 3, which means that local breeding was unidirectional. Local breeding has already enhanced the earliness, yield performance, yield components, and fibre quality (especially maturity) of modern cotton cultivars (according to axis 2). Local breeding has also reduced their vegetative development and boosted their ginning out-turn (according to axis 3). In other words, local breeding has favoured reproductive function to the detriment of vegetative function, and the fibre component to the detriment of the seed component.

Determinate cultivars such as CCA347 and Guazuncho 2 were even earlier and could further enhance the earliness and yield performance of local plant material. In fact, despite their advantage, CCA347 and Guazuncho 2 produced immature fibres, even with early planting (June). Hence for future breeding, it would be preferable to use parents that are not only early flowering and have a short cycle (low node of the first sympodium), but also feature large seeds, high maturity, good fineness and a low yellowness index, since these traits appear to be significantly affected by late planting (Table 5).

4.6. *Interactions and their implications for genotypic screening*

Our first breeding objective consists of identifying genotypes that can be grown in intensive conditions (tilling, optimum fertilization, pest control, and planting date). However, as the proportion of late-planted and infertile fields is increasing (SODECOTON, personal communication), we wonder if the present breeding programme, conducted at a single selection site, would be able to identify genotypes adapted to such constraints. The absence of interaction between cultivar and field practice means that it would be efficient and cost-effective to select indirectly for adaptation to late planting, without a specific programme to be conducted in late planting conditions. This would facilitate future genotypic screenings because genitors to be introduced in the breeding programme could be evaluated in existing field practices.

In contrast, the high level of the other interaction components (field practice–site–year and cultivar–site–year) requires further investigation. Sadras' (1996) findings lead us to think that the field practices and cultivars we evaluated could perform differently across environments depending on the compensatory capacity of cotton plants, which in turn depends on the availability of resources and the length of the recovery period. We need to ensure that determinate growth pattern and extreme earliness do not have a negative impact on the natural adaptive response of the traditional cotton plant to withstand other adverse conditions such as pest infestation, or irregular rainfall.

5. Conclusion

We conducted a 3-year three-location experiment in Cameroon that enabled us to compare three locally selected cotton cultivars and three Latin American cultivars planted at two dates and two plant densities. Our results showed that these three factors acted independently on most traits, enabling us to classify their respective terms separately. Thus, late planting had a highly negative impact on most traits, at both plant and plot scale. In particular, it delayed flowering, reduced yield and fibre quality. High plant density influenced fewer traits, and mainly influenced individual plant traits by enhancing boll shedding and elongating main-stem internodes. Local cultivars have already evolved favourably, as the most recently released cultivar flowered earlier and had better yield components. The local cultivars can be further improved by introgression with highly determinate cottons to make them even better suited to either the shortened rainy season or delayed planting that currently prevail in the cotton-growing area of Cameroon. However, such a strategy requires further investigation to ensure that a higher determinate growth pattern and extreme earliness do not have a negative impact on the natural adaptive response of the traditional cotton plant to withstand other adverse conditions such as pest infestation, irregular rainfall or limited resource availability.

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