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Stress tolerant oil palm varieties

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Abstract

Tolerance to water deficit was evaluated in a group of oil palm varieties planted at two localities in Costa Rica: Coto (South Pacific, with almost no water deficit; less than 200 mm per year), and San Mateo (Central Pacific), with an estimated deficit of nearly 700 mm. A total of 34 crosses were planted at each site in 1994, and their vegetative characteristics, precocity, yield and response to water deficit were evaluated over four years.

Those progenies obtained from Angola, Tanzania and Yangambi populations showed fewer spears (unopened leaves) accumulating during the dry season. The number of lower leaves that desiccated varied widely among progenies; the genotypes of the lines Bamenda and Angola, and those of the wild populations from Malawi and Mobai showed fewer leaves that desiccated as a consequence of the severe water deficit, which can be interpreted as a better tolerance to stress.

The Malawi wild palms, the progenies from Bamenda and Tanzania, and the Mobai derivatives yielded more bunches during the first two years in the field.

Even though all crosses showed some of the negative effects of extreme water deficit at the San Mateo locality, it was evident that some were more tolerant, and this is an indication that they could perform even better under less extreme conditions.

The evaluation of materials tolerant to low temperatures started in the 1970s, after the introduction in 1967 of seeds collected from palms growing wild in the highlands of Cameroon (1000-2000 masl) and Tanzania (1000 masl). Some of the progenies obtained from these introductions (Bamenda x AVROS, Bamenda x Ekona, Tanzania x Ekona and Tanzania x Ekona) have been evaluated since 1990 in several localities in Cameroon, Ethiopia, Kenya, Malawi, Zambia and Ecuador, where they have shown great precocity and better adaptability than local and other commercial varieties.

Oil production potential and growth characteristics of these stress-tolerant varieties have been studied in Coto, under good growing conditions, where they have shown good yield potential, and in some instances even higher oil extraction rates than conventional varieties.

Introduction

The needs of a growing world population have pushed the frontier for oil palm cultivation to areas considered marginal, creating the need to develop new varieties better adapted to areas with severe water deficit and low temperatures.

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The response of oil palm to water deficit is well known, but most studies have been done with a reduced genetic base. On the other hand, not many studies have been conducted to evaluate the performance of the species under low temperature conditions.

ASD of Costa Rica has produced commercial crosses that have shown better adaptability to extreme water deficit in some areas in Costa Rica, and to low temperatures (as well as water deficit) in several countries in Africa. This document summarizes those experiences.

Tolerance to water deficit

The best areas for growing oil palm have well-distributed rainfall throughout the year. Typical monthly rainfall associated with the best yields is around 150 mm (Hemptinne and Ferwerda 1961). The oil palm, however, is able to survive long periods of water deficit. Some morphological and physiological characteristics associated with better tolerance to water deficit are large stem volume (water storage), an extensive radical system, and very efficient stomata control (Maillard et al. 1974; Villalobos et al.; 1991, 1992). Furthermore, the ability to abort some of the developing inflorescences and mobilize reserves, and the large annual variation in yield during the year, helps compensate for lower photosynthetic rates caused by stomata closure (Nouy et al. 1999).

Some very well known indicators of water deficit in oil palm are the accumulation of unopened leaves (spears), bending and breakage of lower leaves that yellow and eventually become desiccated, and bunch failure (Umaña and Chinchilla 1989). Some physiological variables such as relative water content or leaf water potential were not good indicators of water deficit, particularly if taken at noon (Villalobos et al. 1992).

The stomata response to water deficit is rather fast, which implies a reduction in photosynthesis, and therefore in yield potential; so producing genotypes resistant to water deficit seems incompatible with commercial objectives (Villalobos and Rodriguez 1998). However, there are important differences between genetic materials, and some of them could be selected for high tolerance to stress without losing much of their yield potential (Maillard et al. 1974).

Houssou et al. (1992) found that Deli x Yangambi tolerated severe water deficit better (mortality below 3%) than Deli x La Mé (16% mortality). However, important differences were also found among progenies of this latter cross. Nouy et al. (1999) had similar results when these two crosses were evaluated in two sites with annual water deficits ranging from 400 to 700 mm.

This study reports the results of two trials set up to study the response to water deficit of 37 promising genotypes in Costa Rica. One trial was established in Coto (South Pacific), located at 50 masl. Mean annual rainfall in the area is about 3900 mm, with a period of reduced precipitation from December to March, reaching an accumulated annual water deficit of only 200 mm per year or less. Progenies were distributed in two blocks, in plots of eight palms each.

Another trial was planted in the San Mateo area (Alajuela province, Central Pacific) at 250 masl. This area is considered marginal for oil palm cultivation because of the severe water deficit estimated at 700 mm/year, and strong winds during the dry season. Mean annual rainfall is about

2400 mm, and the dry season extends from December to April. Progenies were distributed in one single block, with 12 palms per block.

The productive behavior of the progenies (yield and bunch characteristics) was evaluated at Coto 47 between the fourth and fifth years. Vegetative growth was measured when palms were six years old. Response to water deficit (number of accumulated spears and number of lower leaves desiccated) was evaluated at the San Mateo locality when palms were four years old, and yield characteristics were evaluated during the third and fourth years. Additionally, seven crosses that varied widely in their response to water deficit were selected to measure some other morphological and physiological characteristics: water potential, relative water content, rate of water loss, content of cuticular waxes and specific leaf weight; all measured during the period from November 1997 to April 1998 (Villalobos and Rodriguez 1998).

Results

The accumulation of unopened leaves (spears) was a symptom consistently associated with water deficit. Later, and as water stress became more severe, yellowing of leaves developed and some necrotic zones appeared at the tips of the leaflets. Eventually, some of the lower leaves dried out and the rachis would bend or break.

Progenies obtained from the Angola *dura* population (1.8 spears/palm) and the Tanzania *teneras* (1.7 spears/palm) showed fewer spears accumulated during the dry season. Those progenies descending from the Deli *dura* lines, particularly when combined with AVROS, Ekona and Calabar parents (2.5-2.8 spears/palm) showed more spears accumulating. The Deli origin showed more tolerance when crossed with palms from the Tanzania, Yangambi and La Mé populations (Table 1).

Table 1. Number of spears accumulated per palm in several oil palm crosses. Four-year old palms planted in an area with severe water deficit (mean 700 mm/year) in Costa Rica

Female Progenitor	Male progenitor							
	AVROS	Calabar	Ekona	La Mé	Mobai	Tanzania	Yangambi	Mean
Angola	2.3	2.3	1.6	2.3	1.4	1.0	1.8	1.8
Bamenda	1.9	2.8		2.4	2.9	1.9	2.5	2.4
Deli Dura	2.8	2.5	2.6	2.2	1.7	2.0	2.1	2.3
Deli Ekona	2.1	2.3		2.6	3.3		1.8	2.4
Tanzania	1.6	2.5		2.7	2.6		1.9	2.3
Malawi								1.9
Mean	*2.1*	*2.5*	*2.1*	*2.4*	*2.2*	*1.7*	*2.0*	*2.2*

The mean number of dried lower leaves varied between progenies from 1 to 21. Those crosses of Bamenda and Angola origins, as well palms from the wild Malawi population showed fewer desiccated leaves (4-7.2/palm). Descendants from the Deli *dura* lines and Tanzania (*dura*) had more bent and dried leaves (11-15.5). Differences were not so marked between parent lines and the Mobai source (6.4 dry leaves) (Table 2).

Table 2. Number of lower leaves desiccated during the dry season in 4 year-old palms planted in an area with severe water deficit (estimated at 700 mm.year). Sam Mateo, Costa Rica.

Female progenitor	Male progenitor							
	AVROS	Calabar	Ekona	La Mé	Mobai	Tanzania	Yangambi	Promedio
Angola	4.0	9.0	6.0	5.0	9.0	ND	10.0	7.2
Bamenda	7.0	11.0		ND	1.0	4.0	9.0	6.4
Deli *dura*	10.0	18.0	12.0	6.0	2.0	17.0	12.0	11.0
Deli x Eko.	ND	11.0		6.0	12.0		9.0	9.5
Tanzania	ND	21.0		18.0	8.0		15.0	15.5
Malawi								4.0
Mean	*7.0*	*14.0*	*9.0*	*8.8*	*6.4*	*10.5*	*11.0*	*8.9*

Bunch production during the first two years gives an estimate of yield potential of these genotypes planted in very extreme conditions. The wild palms originated in Malawi (14.2 bunches/palm), and the progenies derived from the female parents Bamenda and Tanzania (11.8 and 9.5 bunches/palm) were the best. At the other extreme, the Deli *dura* palms performed poorly. With respect to parent lines, the original Mobai (14.2 bunches) and Tanzania lines (17 bunches) were the best (Table 3).

Table 3. Number of bunches per palm produced during the first two years in several genotypes planted in an area with severe water deficit (estimated at 700 mm/year) in San Mateo, Central Pacific, Costa Rica.

Female progenitor	Male progenitor							
	AVROS	Calabar	Ekona	La Mé	Mobai	Tanzania	Yangambi	Promedio
Angola	3.7	5.8	8.8	9.2	15.0	14.7	6.2	9.1
Bamenda	7.0	3.7		10.3	21.7	20.7	7.6	11.8
Deli *dura*	3.9	6.8	5.0	11.1	11.4	15.6	6.0	8.5
Deli x Eko.	7.9	8.4		8.5	9.6		9.1	8.7
Tanzania	3.4	9.2		10.3	3.5		11.0	9.5
Malawi								14.2
Mean	*5.2*	*6.8*	*6.9*	*9.9*	*14.2*	*17.0*	*8.0*	*10.3*

The commercial progenies derived from the Deli *dura* population performed poorly, and were severely affected by water stress. Only the Deli x La Mé progenies, and to a lesser degree, those of Deli x Yangambi origins, had acceptable behavior, which is in accord with the findings of others (Maillard 1974, Houssou et al. 1992). The appearance and yield of the Malawi wild palms indicate that they carry genes that make them tolerant to water stress.

Villalobos and Rodriguez (1998) evaluated seven of the genotypes with contrasting responses to water stress in more detail. The most promising populations were Angola, Tanzania and La Mé, as well as some Deli lines. The best crosses were Angola x Tanzania and Angola x La Mé, which had better appearances, higher water potentials at dawn and higher leaf specific weights. The yield potential of these crosses in a less severe environment can be estimated from their performance in Coto (Table 4).

Tolerance to low temperatures

Wild genotypes with tolerance to low temperatures were introduced to Costa Rica by ASD in the 1960s and 70s from two regions in Africa. After an initial evaluation the descendants were planted at several localities.

Bamenda (Cameroon). These materials are derived from wild palms from the high lands of the Northwest Bamenda region (900-1500 masl), with a dry season of about six months. These genotypes show tolerance to some extreme conditions of low temperatures, low solar radiation and water deficit. An initial evaluation showed that they were also very precocious, and some crosses also had tolerance to *Fusarium* wilt (Blaak and Sterling 1996). Some of the characteristics shown by several groups of seeds planted in 1968 appear in table five.

The original population was evaluated during four years, considering bunch characteristics. Bunch conformation in the *dura* palms was considered satisfactory, with a mean of 67% fruits in the bunch, 41% mesocarp to fruit, and 14% kernel to fruit. Oil extraction rate was low (Table 6).

The best palms were used to produce the following *dura* generation, which was planted in 1994 to evaluate fruit yield during the first three years. Vegetative growth and bunch composition were evaluated when palms were 4-5 years old. Palms produced a mean of 94 kg of bunches per palm with an oil extraction rate of 12% (Table 7).

Kigoma (Tanzania). These genotypes originated from seeds collected in 1977 from six palms (5 *teneras* and one *dura*) growing in the wild at mean altitudes (850 masl) in the district of Kigoma, Tanzania. Mean low temperatures in this place are nearly 12° C. These *teneras* were exceptional in the sense that they had very thin shells (Richardson and Chavez 1986), (Table 5).

Descendants from the four *tenera* palms were planted in 1978 in Coto. Mean bunch production per palm varied from 90 to 107 kg during the first four years. Bunches were relatively small (4.6 a 5.2 kg), and the mean number of bunches per palm was 20. *Dura* palms showed good bunch formation with 72% fruit to bunch, 56% mesocarp to fruit and 20% oil to bunch. Oil extraction increased to 27% in the resulting *teneras* (Richardson and Chavez 1986) (Table 6).

Table 4. Vegetative growth and bunch characteristics in several crosses with different response to water stress, Coto (a zone with a very mild water deficit), Costa Rica

Maternal lines	Parental lines	n	FFB	THT	LLG	O/B	OHAY
Angola	AVROS	16	186.9	246	689	24.7	6.7
	Calabar	5	176.1	201	691	25.3	6.3
	Ekona	11	172.6	204	665	21.8	5.4
	La Me	10	156.7	209	673	24.4	5.5
	Mobai	12	132.0	219	621	17.8	3.4
	Tanzania	5	187.8	217	659	21.9	5.9
	Yangambi	16	161.4	220	689	26.4	6.2
	Mean	**75**	**165.9**	**220**	**670**	**23.5**	**5.7**
Bamenda	AVROS	7	163.8	196	656	20.5	4.9
	Calabar	11	130.9	156	626	18.0	3.3
	Ekona	8	153.0	150	642	24.1	5.3
	La Me	8	133.5	151	729	20.5	4.0
	Mobai	11	110.2	156	577	15.7	2.2
	Tanzania	5	185.4	168	661	20.4	5.4
	Yangambi	9	138.1	174	644	20.5	4.5
	Mean	**59**	**140.0**	**163**	**642**	**20.0**	**4.2**
Deli	AVROS	9	167.0	244	730	24.8	5.9
	Calabar	15	169.2	183	705	27.4	6.7
	Ekona	8	171.9	210	668	24.0	6.0
	La Me	12	160.5	182	711	20.1	4.8
	Mobai	14	122.1	186	631	19.2	3.4
	Tanzania	14	169.4	192	741	25.4	6.2
	Yangambi	14	163.6	213	686	27.3	6.5
	Mean	**86**	**159.5**	**199**	**696**	**24.1**	**5.6**
Tanzania	AVROS	15	166.9	208	655	23.7	5.7
	Calabar	15	169.5	172	662	23.2	5.4
	Ekona	9	154.6	175	664	22.8	6.0
	La Me	15	153.7	170	667	21.9	4.8
	Mobai	8	119.4	171	562	21.6	3.4
	Yangambi	16	156.2	179	642	24.5	5.4
	Mean	**78**	**156.4**	**180**	**647**	**23.4**	**5.3**

Mean	AVROS	52	168.0	221	676	22.9	5.8
	Calabar	58	159.7	181	667	23.5	5.4
	Ekona	44	162.0	187	662	23.6	5.7
	La Me	58	149.1	178	691	21.9	4.7
	Mobai	52	116.5	182	596	19.3	3.2
	Tanzania	29	177.1	201	683	23.0	5.8
	Yangambi	70	151.1	196	668	23.5	5.6
General mean		**363**	**153.9**	**192**	**665**	**23.3**	**5.3**

FFB = fresh fruit bunches, THT = trunk height, LLG = leaf length, O/B = oil to bunch; OHAY = oil/ha/year

Several *dura* individuals were selected for planting a new generation in 1994. Yield and growth were evaluated during the same periods indicated for the Bamenda population planted the same year. This new generation showed a high precocity, with mean annual bunch production per palm of 185 kg, a high value of mesocarp to fruit (54%), and a high extraction rate (18.8%) (Table 7).

Table 5. Bunch composition in palms originated from seeds collected in the highlands of Bamenda and Kigoma

	FWT (%)	M/F (%)	Sh/F (%)	K/F (%)	O/M (%)
Bamenda, Cameroon					
Duras	8.4	35.5	51.8	13.1	50.9
Teneras	9.4	68.6	21.2	10.2	45.2
Kigoma, Tanzania**					
Duras	14.5	63.0			
Teneras	13.5	76.3	0.9***	10.0	

* FWT = mean fruit weight, M/F = mesocarp in fruit, Sh/F = Shell to fruit, K/F = kernel to fruit; O/M = oil to mesocarp; ** Richardson and Chaves, 1986; *** Sh/F in mm

Performance of cold-tolerant varieties in extreme conditions

Yields in highlands. Beginning in 1990, ASD of Costa Rica has developed four commercial cold-tolerant varieties (Bamenda x AVROS, Bamenda x Ekona, Tanzania x AVROS and Tanzania x Ekona). These varieties are intended to be planted in the highlands of some African countries like Cameroon, Ethiopia, Kenya, Malawi and Zambia (1000 to 1500 masl). Performance in all these regions has been very satisfactory, where high precocity has been seem even under conditions of high water deficit. Some of these crosses also showed tolerance to *Fusarium* wilt in nursery trials (Chapman et al. 2003; Blaak and Sterling 1996; Steele and Grifee

2001; FAO 2002). Bunch production in these regions has begun in the second to third year after planting, and initial oil production has exceeded that from local *dura* palms by up to four times (Chapman et al. 2003; Steele and Grifee 2001; FAO 2002).

Table 6. Bunch composition of the genotypes of Bamenda and Kigoma evaluated in Coto, Costa Rica

	n	**FWT (%)**	**F/B**	**M/F (%)**	**K/F (%)**	**O/M (%)**	**O/B (%)**
Bamenda, Cameroon							
Duras	219	8.2	67.2	41.2	14.3	44.8	12.9
Teneras	49	6.5	65.5	68.9	14.5	44.1	19.1
Kigoma, Tanzania*							
Duras	96	9.8	71.7	55.7	9.5	50.1	20.2
Teneras	115	7.5	68.3	78.4	10.3	50.3	27.0

n = palms, FWT = mean fruit weight, F/B = fruit to buch, M/F = mesocarp to fruit, K/F = kernel to fruit, O/M = oil to mesocarp, O/B = oil to bunch; * Richardson and Chaves, 1986

Oil yield per palm has been high, even under stress conditions and following very basic agronomic management. At the FAO projects in Malawi and Zambia, oil per palm reached 9-12 liters when palms were 4½ years of age, and increased to 20-30 liters at six years. The best bunch yields were 60 and 150 kg/palm (Chapman et al. 2003; FAO 2002). This performance is exceptional when considering that in those regions in Bamenda, the conventional commercial varieties stabilize their production until they reach 12 years of age (Blaak and Sterling 1996). In Zambia, the local *dura* palms start yielding at eight years of age (FAO 2002).

Table 7. Vegetative characteristics and bunch composition in the *dura* descendants of wild palms brought from the highlands of Bamenda and Kigoma, planted in 1994 in Coto, Costa Rica.

	FFB (kg)	**THT (cm)**	**LLG (cm)**	**M/F (%)**	**O/B (%)**	**OHAY (t)**
Bamenda, Cameroon	93.8	57	472	40.5	11.6	1.5
Kigoma, Tanzania	184.6	68	522	54.0	18.8	4.9

FFB = fresh fruit bunches/palm/year, THT = trunk height, LLG = leaf length, M/F = mesocarp to fruit, O/B = oil to bunch, OHAY = oil/ha/year

Further information on yield potentials of these varieties in shown in table 8, with the results of a trial planted in western Ethiopia (960 masl; annual rainfall, 1800 mm). Performance of the Bamenda x AVROS and Tanzania x AVROS crosses was compared with commercial Deli x Ekona and Deli x AVROS crosses (Blaak and Sterling 1996).

A high precocity of the Bamenda and Tanzania genotypes was evident during the first experiment. After four years in the field these materials were still superior to Deli x AVROS, but not to Deli x Ekona. However, two years later, and following an extremely dry period that induced a high abortion rate, the Bamenda and Tanzania genotypes had better and more stable yields (Table 8).

Table 8. Precocity and number of bunches/plant in four oil palm crosses showing different response to water stress, Gelesha, Ethiopia[1]

Origin	Palms with flowers (%)	Flowers/palm	Bunches/palm		
	1*	**1***	**3**	**4**	**6**
Bamenda x Ekona	70	3.3	5.2	14.3	9.2
Tanzania x AVROS	62	2.3	4.5	12.3	8.6
Deli x Ekona	37	1.2	9.1	16.6	7.3
Deli x AVROS	3	0.1	3.3	10.1	6.9

* Age (years); 1 Blaak and Sterling 1996

In a group of plots planted at Santo Domingo de Los Colorados, Ecuador in 1998, the performance of Bamenda x Ekona and Tanzania x Ekona has been very good, with an accumulated yield of 40-42 t/ha during the first three years, superior to some conventional varieties (33 - 38 t/ha). This region is well known for its prolonged dry period, low solar radiation and rather low temperatures, which only allow for modest yields (Table 9).

Table 9. Initial yields in plots with several commercial oil palm crosses planted in 1998. Santo Domingo, Ecuador

Variety	Palms	t/ha/year			
		2000	2001	2002	Total
Bamenda x AVROS	73	10.3	6.3	12.3	28.0
Bamenda x Ekona	36	5.8	15.4	19.2	40.4
Tanzania x AVROS	57	7.8	10.8	13.5	32.1
Tanzania x Ekona	75	9.2	15.3	17.0	41.5
Deli x AVROS	48	6.5	14.8	11.2	32.6
Deli x Ekona	32	9.4	15.6	13.4	38.3
Deli x Ghana	46	9.8	12.2	15.0	37.0
Deli x La Mé	29	7.2	11.7	13.3	32.2
Mean		*8.2*	*12.8*	*14.4*	*35.4*

Performance under "normal" conditions

Several Bamenda and Tanzania progenies have been planted in Coto, Costa Rica since 1985 to evaluate their yield potentials. Most crosses have performed very well, and some have been superior in terms of oil yields than standard varieties like Deli x AVROS and Deli x Ekona.

Bamenda x AVROS was as good as the control variety in terms of bunch yield, but stem growth rate was lower. Tanzania x AVROS has shown high precocity, but its vegetative growth is vigorous, and oil extraction is slightly lower than in Deli x AVROS. Tanzania x Ekona's bunch yield is similar to the commercial control, but stem growth rate is reduced and oil extraction rate is good (Table 10).

Table 10. Characteristics of several varieties that show different responses to water and low temperature stress, planted in an area with no significant stress (Coto, Costa Rica)

Origin	Palms	FFB (kg)	FFB (t/ha)	THT (cm)	LLG (cm)	M/F (%)	O/B (%)	OHAY(t)
1985 planting								
Deli x AVROS	220	164.3	23.5	415	698	79.2	25.4	6.0
Bamenda x AVROS	115	152.8	21.9	350	745	81.2	25.9	5.7
1991 planting								
Deli x AVROS	36	156.7	22.4	148	611	85.6	27.6	6.2
Tanzania x AVROS	36	155.8	22.3	142	677	83.0	26.6	5.9
Tanazania x Ekona	36	130.9	18.7	110	573	76.1	27.3	5.1
1992 planting								
Deli x AVROS	102	146.2	20.9	211	660	85.3	29.4	6.1
Tanzania x Ekona	85	152.9	21.9	175	665	84.0	29.8	6.5
1998 planting								
Deli x AVROS	36	109.2	17.5	109	672	84.6	32.2	5.6
Deli x Ekona	216	132.0	21.1	94	669	86.8	29.0	6.1
Bamenda x AVROS	36	109.9	17.6	110	572	71.0	21.9	3.8
Bamenda x Ekona	108	132.1	21.1	93	608	77.5	25.7	5.4
Tanzania x AVROS	36	94.3	15.1	129	691	79.7	28.8	4.3

FFB = fresh fruit/palm/year, THT = trunk height, LLG = leaf length, M/F = mesocarp to fruit, O/B = oil to bunch, OHAY = oil/ha/year

Conclusions

It is possible to find tolerance to water deficit within the *Elaeis guineensis* species. Many trials in several localities have shown important differences in the response to this stress within and between groups of palms from different origins. It has been quite clear that other germplasm sources, besides La Mé and Yangambi, also show great potential, which allows expansion of the genetic base used to develop new commercial varieties.

In order to continue searching for new genotypes tolerant to water deficit, by using all the genetic resources available, it is important to establish new trials in areas where conditions are not as severe as those found in some of these trials. The area on the Central Pacific coast of Costa Rica was particularly adverse due to the severe water deficit and the strong winds that severely depressed the yield potential of the genotypes tested.

Tolerance to low temperatures within the *E. guineensis* species can also be found and incorporated into commercial varieties. This idea has been successfully tested in several trials planted in several African countries, and in some areas of America where temperatures fall below those normally accepted as adequate for the crop. Combined stress tolerance (to water deficit and low temperatures for example) also seems possible.

All these experiences open the possibility that new areas, considered marginal so far, can be used for oil palm cultivation. New genetic combinations can also be found that may perform even better than conventional varieties when planted under normal conditions, with little or no stress. Two important objectives to look for are slow stem growth and high mesocarp oil and kernel yields.

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