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EFFECTIVE FLOWERING TIME VARIATIONS IN UPLAND COTTON (*GOSSYPIUM HIRSUTUM*) AT DIFFERENT PLANTING DATES AND STAND DENSITIES IN BENIN

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SUMMARY

Effective flowering time in *Gossypium hirsutum* cotton plants was studied with the aim of enhancing decision making on the best varieties to plant according to the planting date under rainfed cropping conditions. Trials were conducted at two sites in a cotton-growing area of Benin in 2002 and 2003. A split-split plot design with three replicates was used to compare 10 cotton varieties, with different growth cycle lengths and morphology, at three stand densities (42 000, 125 000, 167 000 plants ha^{-1}) and two planting dates (standard planting in June and late planting). The flowering period was characterized by the mean first flower opening date (FF), which is an indicator of flowering earliness, and by the opening date of the last flower giving rise to a first-position boll on fruiting branches (LFP1). Effective flowering time (EFT) was calculated as the difference between LFP1 and FF. EFTs differed markedly in the 10 cotton varieties tested and this parameter could not be predicted on the basis of flowering earliness. Late planting and high planting rates delayed first-flower opening, accelerated last-boll development and reduced the effective flowering time. This latter factor should be taken into account in cotton breeding programmes so that varieties adapted to local rainfall constraints can be recommended to growers while also enhancing crop management sequences.

INTRODUCTION

The cotton varieties most commonly cropped in West and Central Africa generally have a high vegetative growth rate and a relatively long growth cycle (150–170 days). Cotton yields are large when the crop is planted at the onset of the first rains (from mid-May to late June, depending on the region). However, for various reasons (financial, rainfall irregularity, available labour), the crops are usually sown up to mid-July, and most farmers do not plant after this date because the rainy season is already quite advanced, thus substantially reducing the harvest potential. In rainfed cropping conditions, we wondered whether varieties with a shorter growth cycle and lower vegetative growth would enable farmers to obtain a suitable cotton yield even when the crop is sown very late (after 15 July) and, when necessary, at a high planting density.

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We conducted a study in Benin to address this question, comparing commonly cropped varieties with short-cycle varieties. This comparison focused on the phenological cycle of cotton plants, especially the flowering stages: fruiting onset and effective flowering time (period when bolls are initiated). However, cotton has an indeterminate growth habit with overlapping vegetative and fruiting phases, so it is hard to pinpoint the interface between these phases.

Yield earliness is one of the most widely used indicators for assessing growth cycle length. It is measured on the basis of the weight of the first crop harvest (which is carried out when 50 % of the bolls are open) to the total harvest weight – the higher the ratio, the earlier the variety. This indicator is easy to calculate, but differences between varieties are no longer significant when the first harvest date is very late (Bourland *et al.*, 2001).

The number of nodes above the last white flower in the first position on fruiting branches (NAWF) is therefore a more accurate indicator, as proposed by Bourland *et al.* (1992). This indicator can be used to monitor the balance between vegetative and fruiting development; as the fruit load increases, vegetative growth slows down as flowering progresses to the top of the plant. NAWF thus decreases until the plant flowers near the apex (NAWF = 5), a step that signals the completion of flowering and node development. At this point, Bourland *et al.* (1992) found that approximately 95% of the bolls had formed on plants of most modern cotton varieties.

In our study, we focused on the effective flowering period (Sekloka *et al.*, 2007), expressed as the number of days between the beginning of effective flowering and the end. To pinpoint the end of the flowering period, we used the method described in Sekloka *et al.* (2007).

Our study focused on variability in the flowering cycle in 10 short- or long-cycle cotton varieties, according to two planting dates and three stand densities. The effective flowering time could be taken into consideration to facilitate decision making on suitable varieties to be planted under different local rainfall constraints.

MATERIALS AND METHODS

Experimental design

The trials were conducted at two test sites at the Centre de Recherches Agricoles Coton et Fibres du Bénin at Okpara (2°41′E, 9°18′N, 320 m asl altitude), in the middle of a cotton-growing area, and at Cana (2°5′E, 7°6′ N, 89 m asl), in southern Benin. The Okpara site has a unimodal rainfall regime. The rainfall was abundant (Table 1) and regular (Figure 1) in 2002 and 2003. The Cana site has a bimodal rainfall regime. The rainfall was irregular during the cropping season in 2002 and 2003, with a severe drought in September (Table 1, Figure 2). For both years, there was less precipitation available for crops at Cana than at Okpara.

A split-split plot experimental design with three replicates arranged in blocks was used with three factors: two planting dates in main plots, three stand densities in sub-plots and 10 varieties in sub-sub-plots. The first planting date, corresponding to rainfall onset, was carried out in late June. The ‘delayed’ planting date was about

Table 1. Experimental conditions: soil type, planting dates and effective rainfall (eight trials).

Site	Soil†	Year	Planting date	Effective rainfall (mm)‡
Okpara	Tropical ferruginous	2002	June 26	826
			July 17	755
		2003	June 20	858
			July 18	701
Cana	Ferralitic	2002	June 28	499
			July 31	356
		2003	June 24	406
			July 24	461

†The two soil types had low organic matter content.
‡Effective rainfall is the cumulated rainfall from 10 days before planting until the first harvest.

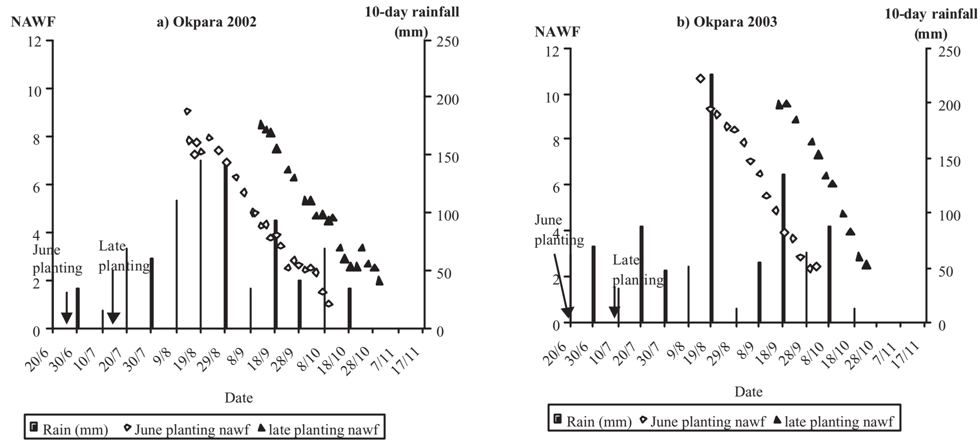

Figure 1. Okpara: satisfactory rainfall and NAWF patterns (2002 and 2003) (mean levels recorded for six varieties: Chaco 520, Irma A 1042, Mar 88-214, Oultan, S 188 and Stam 18 A. NAWF: number of nodes above the last white flower in the first position on fruiting branches.

3–5 weeks after the first date, from mid to late July. The three stand densities were 42 000 plants ha^{-1} (0.8 × 0.3 m spacing), 125 000 plants ha^{-1} (0.4 × 0.2 m) and 167 000 plants ha^{-1} (0.4 × 0.15 m).

The 10 cropped varieties differed markedly in terms of morphology and growth cycle (Table 2). Mar 88–214 was the earliest variety and Irma A1042 was the latest. The Oultan variety has very different morphological features, i.e. clustered habit with very short internodes and fruiting branches, in comparison to varieties conventionally cropped in Africa, such as Stam 18 A and Irma A 1042, which have much more vigorous vegetative growth.

The basic plots (14.4 m^2) were set up with three or six 6 m rows, depending on the planting density. Seedlings were thinned to one plant per hole. Fertilizers were applied according to extension service recommendations: 200 kg ha^{-1} complete fertilizer (N:P:K; 14:23:14 formula) and, only in the case of early planted crops, 50 kg ha^{-1}

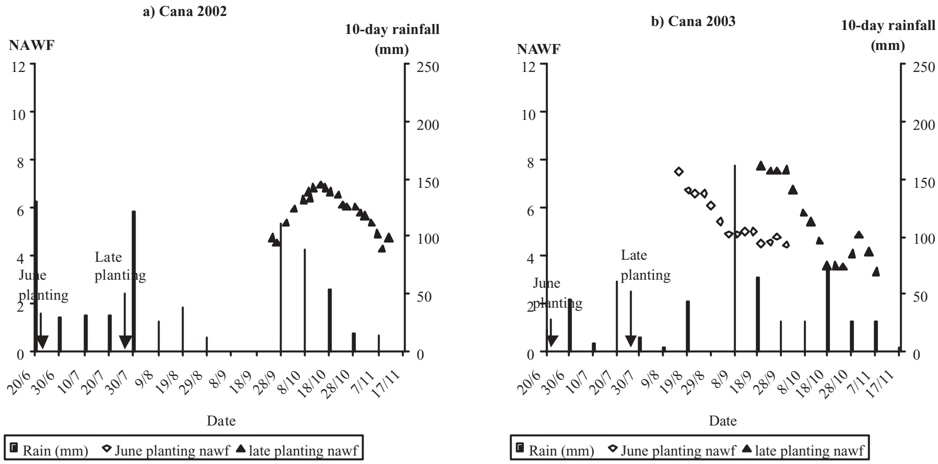

Figure 2. Cana: irregular rainfall and NAWF patterns (2002 and 2003) (mean levels recorded for six varieties, i.e. Chaco 520, Irma A 1042, Mar 88-214, Oultan, S 188 and Stam 18 A). NAWF: see figure 1.

Table 2. The 10 varieties tested in Benin: morphological types and flowering earliness.

Variety	Origin	Cropping zone	Flowering	Habit
Mar 88-214	USA	USA	Early	Compact-short branches
Oultan	Uzbekistan	Iran	Early	Clustered
Chaco 520	Argentina	Argentina	Early	Compact
Rockett	USA	USA	Intermediate	Compact-short branches
Guazuncho 2	Argentina	Argentina	Intermediate	Compact
H 279-1†	Togo – Benin	Benin	Late	Slender-arborescent
Irma 772	Cameroon	Senegal	Late	Slender-short branches
S 188	Nicaragua	Nicaragua	Late	Okra leaf-arborescent
Stam 18 A†	Togo – Benin	Benin	Late	Slender-arborescent
Irma A 1042	Cameroon	Cameroon	Very late	Slender-arborescent

†H 279-1 and Stam 18 A are progeny of the same cross.

urea applied at flowering (following local recommendations to farmers). Ten pesticide applications were made to avoid shedding of fruiting organs due to insect infestation.

Variables measured and analysed

Plants in the middle rows were monitored in the basic plots (second row in plots with three rows, third and fourth rows for plots with six rows).

The flowering cycle of the cotton varieties was described on the basis of flowering onset parameters (FF: mean first flower opening date), behaviour during the flowering phase (NAWF), the end of the flowering period (date of the last effective flower: LEF), and the effective flowering time (EFT). However, flowering parameters for the first planting date could not be recorded at Cana in 2002.

FF was determined by counting the number of white flowers per plot as soon as the first flowers appeared. This indicator corresponds to the date when the cumulated daily count is equal to the number of plants in the row, as expressed by the number of days post-emergence. This indicator represents flowering earliness.

NAWF was recorded by the method described in Bourland *et al.* (1992). This was done twice a week from flowering onset until the end of the flowering period. For every measurement, NAWF was determined on five consecutive plants per plot bearing a first-position white flower on a fruiting branch. We also noted the opening date of the LEF (i.e. giving rise to a harvestable boll) by measuring the opening date of the last flower giving rise to a first-position boll on the highest fruiting branch (LFP1), according to the method described in Sekloka *et al.* (2007). EFT in days was calculated as the difference between LFP1 and FF. EFT represents the period during which opened flowers could develop into harvestable bolls.

We used the mixed procedure in the SAS® software package (SAS-Institute, 1988) to analyse the data in order to estimate and test the effects and interactions between the three factors, while taking into account the three dimensions of the embedded plots. The factors (planting date, stand density and variety) were considered as fixed effects. Multiple comparisons of means were carried out using the Tukey-Kramer test (1956) at the 5 % probability level. The same level was used for confidence intervals and standard errors.

RESULTS

Flower development in the trials

NAWF was monitored to help in understanding how flowering occurred in the experiments. Bourland *et al.* (1992) have proposed a representation of the NAWF pattern in normal growing conditions. According to them, the number of nodes upon which a flower develops in the first position on fruiting branches decreases steadily with the number of days after planting.

At the Okpara site, NAWF decreased steadily and almost linearly over the time course of the study (Figure 1). The NAWF pattern was representative of normal growth conditions, according to the target curve previously described (Bourland *et al.*, 1992; Oosterhuis *et al.*, 1996). Vegetative growth was more vigorous in 2003, with flowering onset at NAWF = 10–11, whereas it was in the range 8–9 in 2002.

At the Cana site, the NAWF curve highlighted the development of cotton plants disturbed by irregular climatic conditions (Figure 2). The NAWF curve for the late planting trials in 2002 revealed that the crop had undergone stress. After a slow start, vegetative growth recovered when the rains began in October, but this growth stopped at a higher NAWF level (4–5) than in Okpara (2–3), indicating that the plants had not achieved their full growth potential. In 2003, the NAWF curves showed that flowering had been more regular, but vegetative growth began again in September in plants sown in June, and in early November for those planted in July.

Effect of planting date and stand density on flowering

The first flowers appeared later when the plants had been sown late and at a high planting rate (Table 3). The first flowers opened earlier for the June planting trials at

Table 3. Significant effect of delayed planting and high stand density on the first-flower opening date (in number of days post-emergence).

	Stand density (plants ha^{-1})			
Planting date	42 000	125 000	167 000	Mean
June	57.0	57.5	59.1	57.9
July	59.2	61.3	62.4	61.0
Mean	58.1	59.4	60.7	59.4

s.e. associated to planting date by stand density interaction is 1.0; *s.e.*s associated to planting date and stand density are 1.9 and 0.9 respectively.

Table 4. Effects of planting date and stand density on the opening date of the last effective flower (in number of days post-emergence).

	Stand densities at Okpara (plants ha^{-1})				Stand densities at Cana (plants ha^{-1})			
Planting date	42 000	125 000	167 000	Mean	42 000	125 000	167 000	Mean
June 2002	81.6	77.2	77.6	78.8	-	-	-	-
July 2002	80.0	75.5	73.1	76.2	88.1	90.4	87.4	88.6
June 2003	90.0	88.0	85.6	87.9	86.3	88.7	87.2	87.4
July 2003	82.0	77.7	77.8	79.2	81.0	77.1	76.9	78.3
Mean	83.4	79.6	78.5	80.5	85.1	85.4	83.8	84.8

s.e. associated to year by location by planting date by stand densities interaction is 3.6; *s.e.*s associated to planting date and stand density are 1.5 and 0.9 respectively.

a stand density of 42 000 plants ha^{-1}. These differences in first flower opening dates were found to be highly significant when comparing planting dates ($p < 0.01$) and stand densities ($p < 0.0001$).

LFP1 was, however, earlier in the late planting trials (Table 4). This effect was significant for both sites in 2003. High stand densities had the same acceleration effect, but the differences were not always significant. The statistical analysis revealed a highly significant ($p < 0.01$) year × site × planting date × density interaction for all sites and trials. This interaction could be explained by the absence of significant differences between planting dates at Okpara in 2002 (at all stand densities) and at Cana (at 42 000 plants ha^{-1}).

EFT was generally shorter with late planting and high stand densities (Table 5). Overall, the effective flowering time ranged from 12.2 to 34.9 days, depending on the stand density and planting date. The highest EFT values were obtained at low stand density (42 000 plants ha^{-1}) when the plants were sown in June. Differences between planting dates were significant in 2002 but not in 2003. The highly significant ($p < 0.01$) year × site × planting date × density interactions could be explained by the variations in differences noted at Okpara, and the lack of significant differences in 2003.

Table 5. Significant effect of late planting and high stand density on the effective flowering time (in days).

Planting date	Stand densities at Okpara (plants ha^{-1}) 42 000	125 000	167 000	Mean	Stand densities at Cana (plants ha^{-1}) 42 000	125 000	167 000	Mean
June 2002	29.8	25.8	22.6	26.1	–	–	–	–
July 2002	19.7	13.7	12.2	15.2	21.7	14.6	13.4	16.6
June 2003	25.8	21.4	19.6	22.2	34.9	24.7	22.6	27.4
July 2003	23.0	17.7	14.1	18.3	30.0	29.5	25.9	28.5
Mean	25.6	19.7	17.1	20.4	28.9	22.9	20.6	24.1

s.e. associated to year by location by planting date by stand densities interaction is 3.7; and *s.e.*s associated to planting date and stand density are 1.6 and 0.9 respectively.

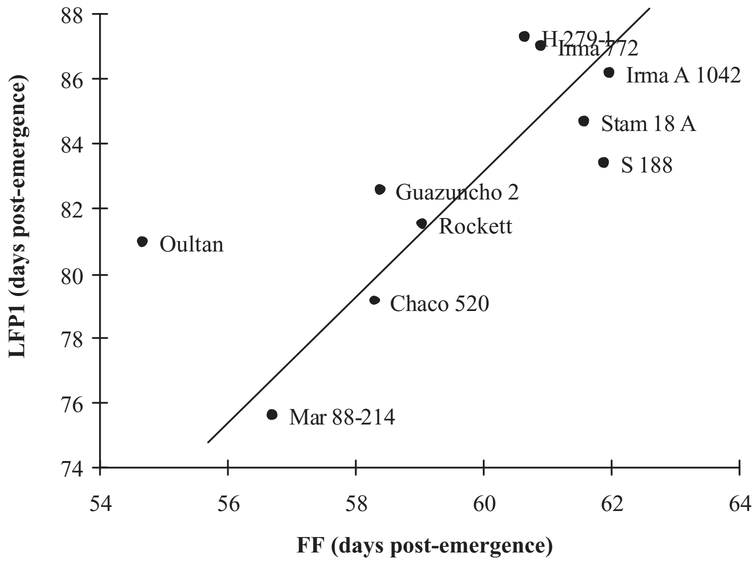

Figure 3. Variability in opening date of the last effective flower (LFP1) according to the mean first flower opening date (FF). The dotted line represents a regression across all varieties except Oultan. $R^2 = 0.71$, $n = 10$.

Genetic variability of flowering indicators

Onset and end of flowering (FF and LFP1). The 10 tested varieties showed high variability with respect to the FF and LFP1. Four behavioural groups were noted (Figure 3):

– Mar 88-214: flowering began and ended early
– Irma A 1042, Irma 772, Stam 18 A, H 279-1 and S 188: flowering began late and ended late
– Guazuncho 2, Chaco 520 and Rockett: flowering patterns were midway between the two above groups
– Oultan: flowering began early and ended quite late.

Table 6. Varietal effects on the effective flowering time (in days).

		Year		
Variety	Flowering	2002	2003	Mean
Mar 88-214	Early	21.2	15.8	18.5
Oultan	Early	26.5	22.1	24.3
Chaco 520	Early	21.8	18.4	20.1
Rockett	Intermediate	23.4	21.5	22.4
Guazuncho 2	Intermediate	25.9	22.1	24.0
H 279-1	Late	27.2	25.4	26.3
Irma 772	Late	25.3	26.4	25.8
S 188	Late	22.5	20.1	21.3
Stam 18 A	Late	24.2	21.4	22.8
Irma A 1042	Very late	23.8	26.2	25.0
Mean		24.2	21.9	23.0

s.e. associated to year × variety interaction is 1.3, and *s.e.* associated to varietal effect is 1.2.

The analysis of variance revealed that the variety or genetic effects were more significant than the interaction effects. For the FF, we obtained an F-test value of 2.17 (with 9 and 432 *d.f.*) for the year × site × variety interaction, and 3.42 (same *d.f.*) for the year-planting date × variety interaction – these two values were lower than that obtained for the varietal effect (F-test = 109.75, same *d.f.*). For LFP1, only the year × variety interaction was significant, with an F-value of 2.35 (with 9 and 414 *d.f.*) compared to 17.96 (same *d.f.*) for the varietal effect.

Effective flowering time. The values of EFT differed markedly between varieties. On average, EFT reached 26 days for H 279-1, the variety grown commercially in Benin, and only 18 days for Mar 88-214 (Table 6). EFT was lower for Mar 88-214, Chaco 520, S188 and Rockett. For all varieties except Mar 88-214 (5.4 days difference), EFT did not significantly vary between 2002 and 2003. The behaviour of Mar 88-214 or Irma varieties, with superior EFT in 2003, could explain the significant year × variety interaction, although the overall variety effect was much higher (F-test = 8.02 with 9 and 414 *d.f.* for the variety effect compared to 2.12 with the same *d.f.* for the interaction).

Figure 4 compares FF with EFT: it shows how flowering earliness is related to flowering time. The patterns on this graph highlights three new behavioural groups that did not exactly overlap with the four groups obtained when comparing the onset and end of flowering variables (Figure 3):

– The regression line obtained for Mar 88-214, Chaco 520, Rockett, Guazuncho 2, H 279-1, Irma A 1042 and Irma 772 linked EFT with FF. Varieties that flowered early, such as Mar 88-214 and Chaco 520, had a short flowering time, while varieties that flowered later, such as IRMA A 1042, Irma 772 and H 279-1, had a much longer flowering period. Rockett and Guazuncho 2 showed an intermediate behaviour.

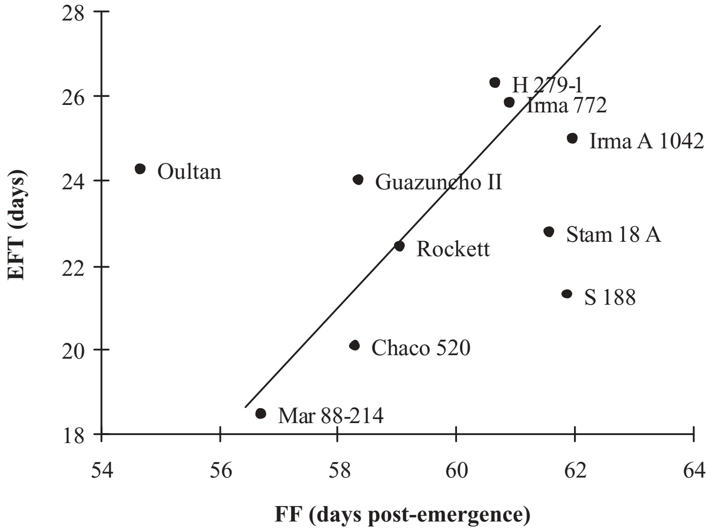

Figure 4. Variability in effective flowering time (EFT) according to the mean first flower opening date (FF). The dotted line represents a regression across all varieties except Oultan, Stam 18 A and S 188. $R^2 = 0.73$, $n = 7$.

– Stam 18 A and S 188 had a shorter flowering time relative to their flowering earliness.
– Oultan combined very early flowering and a long effective flowering time.

DISCUSSION AND CONCLUSION

The results reported in this study suggest that the effective flowering time (EFT) shortens as the planting date is delayed and the stand density increases. Planting crops late at high stand densities seems to delay first flower opening and to accelerate the opening of the last flower giving rise to a harvestable boll.

It is likely that the stand density effect is associated with increased between-plant competition for water and trophic factors. Several previously published results confirm that high stand densities increase the height at which the first fruiting branch is formed and delay flowering onset (Jost and Cothren, 2000; Vories and Glover, 2002; Smith *et al.*, 1979).

To interpret the late planting results, we have to consider that July falls in the middle of the rainy season and that humid conditions can delay flowering onset. Temperatures are generally lower during this period as the skies are often overcast and nitrogen mineralized in the soil with the first rains has already been taken up by the weed cover. Moreover, the flowering period ends prematurely when the rains stop at the end of the cotton growth cycle.

Our results showed that EFT was under genetic control and not always linked with flowering earliness. This indicator differentiated close genotypes such as H 279-1 and Stam 18 A, or varieties with comparable flowering earliness such as Oultan and Mar 88-214.

EFT was found to be an interesting trait that could be taken into account when choosing varieties to be cropped according to local rainfall constraints, and also for enhancing crop management sequences. Our results thus showed that the commonly cropped H279-1 variety had a longer EFT than STAM 18A. This finding confirms the recent recommendation to the farmers to plant H279-1 – a recommendation supported by tests showing that the H 279-1 genotype yielded better over a wide range of on-farm situations than STAM 18A, a variety derived from the same cross.

Finally, the intraspecific variability of EFT noted in this study is broad enough to be utilized by breeders. This indicator is relatively easy to obtain and to use since it is determined by monitoring the opening date of the first flower and estimating the date of the last effective flower as described by Sekloka *et al.* (2007). A following paper will show that EFT may contribute, with other indicators of earliness, to determine better the yield potential of a variety.

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