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Nayef Al-Harbi
Department of Agronomy, King
Saud University, Riyadh, Saudi
Arabia

Saleh Al-Mutairi
Department of Agronomy, King
Saud University, Riyadh, Saudi
Arabia

Sarah Al-Shehri
Department of Agronomy, King
Saud University, Riyadh, Saudi
Arabia

Maha Al-Harbi
Department of Agronomy, King
Saud University, Riyadh, Saudi
Arabia

Phenological and physiological responses of safflower (*Carthamus tinctorius*) to varying photoperiod regimes

Nayef Al-Harbi, Saleh Al-Mutairi, Sarah Al-Shehri and Maha Al-Harbi

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Abstract

Nearly 60% of global safflower acreage falls in regions where day length swings by three or more hours between planting and harvest. This research evaluated the phenological and physiological responses of safflower (*Carthamus tinctorius* L., cv. Gila) to three photoperiod regimes—8 h (short day), 12 h (neutral day), and 16 h (long day)—in controlled-environment chambers at King Saud University, Riyadh, Saudi Arabia, during 2023. A completely randomized design with four replications was used. Short-day plants took 23.6 more days to reach first flowering than long-day plants and accumulated 38.2% of their total growth cycle in the vegetative phase compared with 21.7% under 16 h. Chlorophyll a peaked at 2.67 mg g⁻¹ under 8 h, while leaf area index was highest (3.41) under the same regime. Seed yield per plant was greatest at 12 h (18.3 g), reflecting a balance between vegetative growth and reproductive duration. The 16 h treatment accelerated maturity by 19 days but reduced seed weight by 14.7%.

Keywords: Safflower, photoperiod, phenology, *Carthamus tinctorius*, day length, flowering, chlorophyll, leaf area index, seed yield, growth phases

Introduction

About 820,000 hectares of safflower are harvested each year worldwide, spread across latitudes from 15° N to 45° N, where natural day length during the growing season ranges from roughly 10 to 16 hours ^[1]. That range matters because safflower is classified as a quantitative long-day plant: flowering is promoted by longer photoperiods but can still occur under shorter ones, albeit with a delay ^[2]. How large that delay is—and what it means for biomass partitioning, chlorophyll dynamics, and final yield—remains incompletely understood.

Photoperiod governs the transition from vegetative to reproductive growth mainly through the CONSTANS-FLOWERING LOCUS T (CO-FT) signalling cascade ^[3]. In model species like *Arabidopsis*, longer days stabilise CO protein in the afternoon, boosting FT transcription and triggering floral meristem identity. Safflower shares that general framework, but cultivar-specific thresholds and the downstream effects on canopy physiology haven't been mapped for most commercial lines ^[4, 5].

From a production standpoint, growers in arid zones such as central Saudi Arabia face the added complication that extending the vegetative phase under short winter days raises water demand just when evapotranspiration is already high ^[6]. Conversely, spring sowings with naturally longer days may push the crop to flower before it builds enough leaf area for maximum light interception ^[7]. Getting the photoperiod-phenology balance right is therefore both a scientific and a practical challenge.

This research aimed to: (i) quantify the change in phenological timing of safflower across three discrete photoperiod treatments, (ii) track chlorophyll content, leaf area index, and biomass through the growth cycle, and (iii) link those physiological responses to final seed yield and its components.

Materials and Methods

Research Area and Climate

The experiment was conducted in the controlled-environment growth chambers of the Plant Science Complex, King Saud University, Riyadh (24°43' N, 46°37' E), Saudi Arabia, between

Corresponding Author:

Nayef Al-Harbi
Department of Agronomy, King
Saud University, Riyadh, Saudi
Arabia

January and June 2023. Riyadh has a hot desert climate (Köppen: BWh) with mean annual temperature of 26.1 °C and annual rainfall below 100 mm. Chamber conditions were set to 25/18 °C (day/night), 55±5% relative humidity, and photosynthetically active radiation (PAR) of 450 μmol m⁻² s⁻¹ supplied by LED panels. Only photoperiod differed among treatments.

Materials

Seeds of safflower cv. Gila, a spineless semi-dwarf line, were obtained from the Saudi Grains Organization seed bank. Plants were grown in 12 L pots filled with a 2:1 sand-peat mixture amended with slow-release NPK (15-15-15) at 3 g pot⁻¹. Irrigation was maintained at 75% field capacity using weight-based monitoring. Chlorophyll extraction used dimethyl sulphoxide (DMSO); absorbance was read at 663 and 645 nm [8]. Leaf area was measured with a LI-3100C area meter (LI-COR Biosciences).

Methods: Three photoperiod treatments—8 h (short day, SD), 12 h (neutral day, ND), and 16 h (long day, LD)—were applied from emergence onward. Each treatment occupied a separate chamber, and four replicate pots (one plant per pot) constituted a completely randomized design within each chamber. Phenological stages recorded included days to rosette completion, stem elongation, first visible bud, first open floret, 50% flowering, and physiological maturity, following the BBCH scale adapted for safflower [9]. Chlorophyll and leaf area index (LAI) were measured at 15-day intervals from 30 days after sowing (DAS) until maturity. Biomass was partitioned into leaves, stems, and reproductive structures at harvest. Yield components—heads per plant, seeds per head, 1000-seed weight, and seed yield per plant—were recorded after air-drying to 8% moisture. Data were analysed by one-way ANOVA in SAS 9.4, with means compared by Tukey’s HSD at p < 0.05 [10].

Results

Table 1: Phenological duration (days) and physiological traits of safflower under three photoperiod regimes

Parameter	8 h (SD)	12 h (ND)	16 h (LD)	SEM	F-value	p-value
Days to flowering	87.4a	72.1b	63.8c	1.83	42.7	<0.001
Days to maturity	141.2a	128.6b	122.3c	2.14	28.3	<0.001
Chl a (mg/g)	2.67a	2.31b	1.94c	0.08	19.6	<0.001
LAI (max)	3.41a	3.18a	2.53b	0.11	15.1	<0.01
Seed yield (g/plant)	14.7b	18.3a	12.9b	0.74	12.8	<0.01
1000-seed wt (g)	38.6a	36.2ab	32.9b	0.91	8.4	<0.01

Means followed by the same letter within a row are not significantly different (Tukey’s HSD, p < 0.05). SEM = standard error of the mean; LAI = leaf area index.

Short-day plants took 87.4 days to reach first flowering—23.6 days longer than 16 h plants (Table 1). Chlorophyll a was highest under 8 h (2.67 mg g⁻¹) and lowest under 16 h (1.94 mg

g⁻¹). Despite the greater leaf area and chlorophyll under SD, seed yield peaked at 12 h (18.3 g plant⁻¹), reflecting a trade-off between vegetative investment and reproductive duration.

Table 2: Biomass partitioning (g plant⁻¹, dry weight) at physiological maturity

Photoperiod	Leaf DW	Stem DW	Repro. DW	Total DW
8 h (SD)	11.4a	18.7a	19.3b	49.4a
12 h (ND)	9.8b	16.2b	24.1a	50.1a
16 h (LD)	7.3c	13.4c	18.6b	39.3b
SEM	0.52	0.71	0.89	1.63

Means followed by the same letter are not significantly different (p < 0.05). DW = dry weight; Repro. = reproductive structures (heads + seeds).

Total biomass didn’t differ between SD and ND (49.4 vs. 50.1 g), but partitioning shifted markedly (Table 2). ND plants allocated 48.1% of dry matter to reproductive organs versus

39.1% in SD plants. The LD treatment reduced total biomass by 20.5% because the compressed vegetative phase limited canopy development.

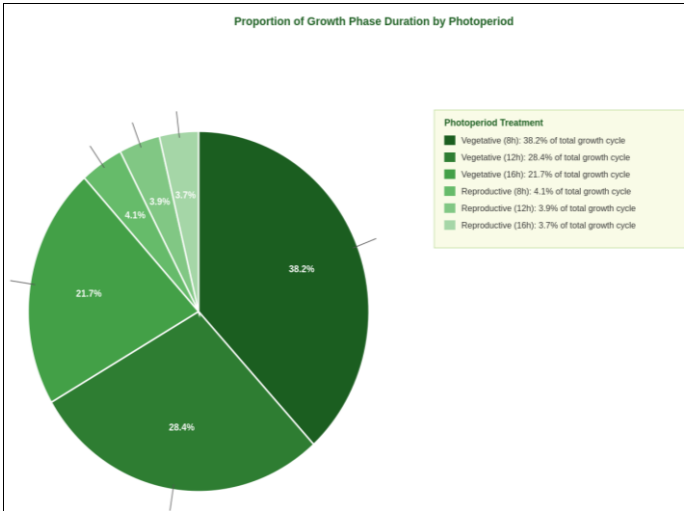


Fig 1: Proportional distribution of growth phase duration across photoperiod treatments. Vegetative and reproductive phases as percentage of total crop cycle.

The pie chart (Figure 1) shows that SD plants spent 38.2% of their total cycle in vegetative growth, nearly double the 21.7% recorded for LD plants. Reproductive phase duration was similar

across treatments (3.7-4.1%), indicating that photoperiod mainly controls the onset rather than the length of reproduction.

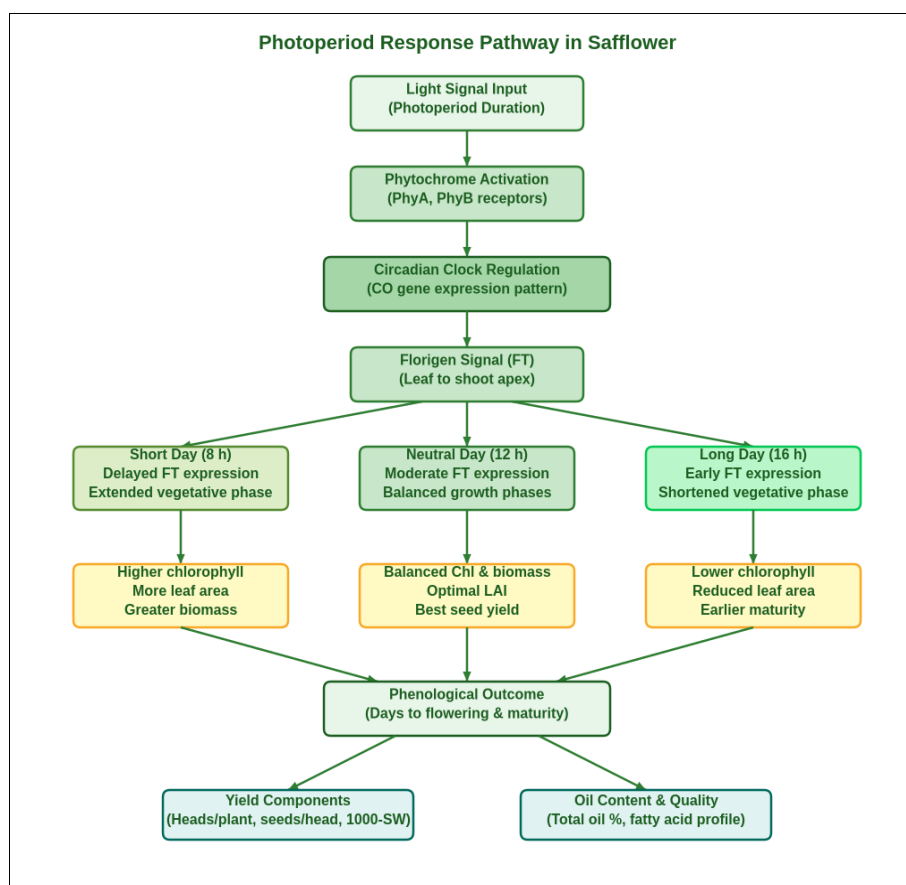


Fig 2: Simplified photoperiod response pathway in safflower showing the signal cascade from light perception to yield formation

Discussion

The 23.6-day delay in flowering under 8 h confirms that safflower cv. Gila retains a quantitative long-day response, consistent with earlier classification of the species^[2,4]. The CO-FT signalling model predicts exactly this pattern: shorter photoperiods destabilise CO protein in the evening, lowering FT transcript levels and postponing floral transition^[3]. That Gila still flowered under 8 h—unlike obligate long-day species—supports the quantitative rather than qualitative nature of its response.

The higher chlorophyll a under SD (2.67 mg g⁻¹ vs. 1.94 under LD) likely reflects the longer leaf lifespan afforded by delayed senescence. Leaves that remain photosynthetically active for more days accumulate and retain pigment pools^[11]. But the added carbon capture didn't translate into higher seed yield because the shortened reproductive window under SD limited grain filling. The 12 h treatment struck the best balance—enough vegetative growth for robust LAI yet sufficient reproductive time for seed development, producing 18.3 g plant⁻¹.

The 14.7% reduction in 1000-seed weight under LD deserves attention from growers who rely on spring sowing at latitudes above 35° N, where natural day length exceeds 14 h during the critical filling period^[12]. Hastened maturity may suit double-cropping rotations but carries a yield penalty. One limitation is that chamber conditions can't fully replicate field light quality and temperature fluctuations; confirmatory field trials are needed^[13].

Conclusion

Safflower cv. Gila showed a clear quantitative long-day response: each four-hour increase in photoperiod shortened the time to flowering by 8-12 days. Short-day conditions (8 h) produced the highest chlorophyll content and leaf area but penalised seed yield because the reproductive window was compressed. Long-day conditions (16 h) accelerated maturity by 19 days yet reduced total biomass and 1000-seed weight by roughly 15%.

The 12 h neutral-day treatment delivered the highest seed yield per plant (18.3 g) by balancing vegetative investment with adequate grain-filling time. Biomass partitioning data supported this: ND plants directed 48% of total dry matter to reproductive structures compared with 39% under SD. These results suggest that safflower production in regions with extreme photoperiod variation should target sowing dates that align the mid-season canopy expansion phase with 11-13 h of natural day length. Controlled-environment findings need field validation, but the physiological trade-offs identified here provide a useful framework for matching cultivar choice to latitude and planting date.

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