Role of Planting Date on Yield and Cannabinoid Content of Day-neutral and Photoperiod-sensitive Hemp in Georgia, USA

Timothy Coolong[1], Kate Cassity-Duffey[1], and Noelle Joy[1]

Keywords. **autoflower, cannabidiol, *Cannabis indica*, *Cannabis ruderalis*, *Cannabis sativa*, tetrahydrocannabinol**

Abstract. **Industrial hemp (*Cannabis sativa*) cultivars used for flower, fiber, or seed production are usually considered short-day plants and flower in response to photoperiod. However, some cultivars of hemp are day-neutral, where flower induction may be independent of daylength. Day-neutral cultivars of hemp were planted before recommended dates and studied in field experiments conducted in Watkinsville, GA, in Spring 2020 and 2021. Day-neutral cultivars (Pipeline and Maverick) and photoperiod-sensitive cultivars (Von and Whitehouse Cherry) were planted on 9 and 25 Apr and 11 and 28 May to determine the impact of planting date on hemp flower yield and quality. Planting date did not impact yield of the photoperiod-sensitive cultivars, but yields of day-neutral cultivars decreased as planting date progressed. Average yields of photoperiod-sensitive plants were greater than the day-neutral cultivars in both study years. Cannabinoid concentrations in flowers were affected by cultivar and study year but were not impacted by planting date. Cannabidiol was the most prevalent cannabinoid in flower tissue with concentrations ranging from 6.5% to 10.5%. Flower biomass yields suggest that the spring hemp planting season may be extended using day-neutral cultivars in the southeastern United States.**

The Agriculture Improvement Act (Farm Bill) of 2018 permitted widespread industrial hemp (*C. sativa*) production in the United States [US Department of Agriculture (USDA) 2019]. Industrial hemp is classified as *C. sativa* with total potential tetrahydrocannabinol (THC) concentration 0.3% or less on a dry weight basis. Plants with a total THC concentration above 0.3% are classified as marijuana and subject to federal prohibition in the United States (USDA 2019). In 2021, 33,500 acres of hemp were planted for open field production in the United States, with ~16,000 acres grown for the floral market and the remainder grown for seed and fiber production (USDA 2022). Open field production of hemp for extraction of phytocannabinoids had an estimated value of $623 million in 2021 (USDA 2022). Hemp plants grown for the floral market are often intended for extraction of cannabidiol (CBD) or cannabigerol (CBG), nonintoxicating cannabinoids used for therapeutic purposes (Morales et al. 2017). Most licensed hemp producers in Georgia, USA, have sought to grow crops for the floral market (Hollifield T, personal communication) due to the relatively high value of the crop.

Hemp grown for fiber or seed production may use either dioecious or monoecious cultivars (Faux et al. 2016; Stringer 2018); however, plants destined for the flower market are typically dioecious, using only female plants, which can have many times the concentration of cannabinoids compared with males (Clarke and Merlin 2016). In the absence of pollination, female flowers continue to grow and produce greater concentrations of cannabinoids, as no resources are devoted to seed production (Small and Naraine 2016).

Hemp is classified as a qualitative short-day plant that flowers in response to shortening photoperiods. Hemp development occurs over a continuum that may be classified into juvenile (vegetative), photoperiod inductive (vegetative and flowering), and harvest maturity (anthesis) stages (Amaducci et al. 2008a; Hall et al. 2012; Lisson et al. 2000). After emergence, hemp plants typically have a short vegetative phase, also referred to as a "juvenile phase." This is followed by a photoperiod-dependent phase where much of the vegetative growth occurs before flower induction (Lisson et al. 2000). The length of the juvenile phase varies and can be impacted by genetics and temperature. The juvenile phase has been reported to be as short as 13 d after emergence in some cultivars (Amaducci et al. 2008b). After the juvenile phase, hemp cultivars may initiate flowering when exposed to photoperiods of less than 14 to 16 h. Small (2015) noted that flowering in hemp was highly dependent on the latitude for which it was adapted, with populations selected for far northern latitudes flowering and producing seeds shortly after planting. Hall et al. (2012) reported that temperature

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[1]Department of Horticulture, The University of Georgia, 1111 Miller Plant Sciences, Athens, GA 30602, USA

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T.C. is the corresponding author. E-mail: tcoolong@uga.edu.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
29,574	fl oz	μL	3.3814×10^{-5}
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
1	micron(s)	μm	1
0.0254	mil(s)	mm	39.3701
28.3495	oz	g	0.0353
28,350	oz	mg	3.5274×10^{-5}
1	ppm	$mg \cdot L^{-1}$	1
6.8948	psi	kPa	0.1450
(°F − 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

and photoperiod impacted time to flowering under tropical environmental conditions, although results were cultivar dependent. When hemp is planted during periods of short days, it may flower prematurely. This lack of vegetative growth may result in yield reductions (Amaducci et al. 2008a; Hall et al. 2012). Therefore, plantings may be limited to late spring and summer when daylength allows for adequate vegetative growth before flowering. Although the impact of temperature and photoperiod has been investigated in hemp grown for fiber or seed production (Amaducci et al. 2008a, 2008b, 2012; Tang et al. 2016), there is less information on the impact of environmental conditions on flower yield in hemp.

Some hemp plants exhibit a day-neutral flowering trait. These plants may be grown closer to the equator, where daylength remains consistent throughout the year, and in higher northern latitudes where cold weather is coupled with short growing seasons (Small 2015). Common name (*Cannabis ruderalis* or *C. sativa* ssp. *ruderalis*) is associated with haplotypes from high latitudes (>43°N) (Zhang et al. 2018), which may be a source of day-neutral traits in some hemp cultivars (Green 2005; Small 2015).

Hemp producers in Georgia may benefit from planting in early spring, when temperatures are mild. However, given the photoperiodic requirements of hemp, planting is recommended for late May and June, when the daily photoperiod in much of the state is near 14 h (Coolong 2020). Linder et al. (2022) reported that yield decreased when a photoperiod-sensitive cultivar, BaOx, was planted between 11 May and 7 Jul in North Carolina. Typically, 11 May would be the earliest planting period for growers in Georgia, with a photoperiod-sensitive cultivar. However, it is not known if growers can use day-neutral cultivars to be able to plant in the field during shorter photoperiods in early spring, taking advantage of mild air temperatures.

The objectives of this study were to determine if day-neutral hemp cultivars were suitable for planting in early spring in Georgia and how planting date may affect growth and development in hemp.

Materials and methods

The study was conducted at The University of Georgia (UGA) Durham Horticulture Research Farm in Watkinsville, GA, USA (lat. 33°5′N, long. 83°3′W) in Spring and Summer 2020 and 2021. The soil is a Cecil sandy loam series (0% to 2% slope) (USDA 2005). Before planting, soil pH ranged from 5.8 to 6.1 with an average of 152, 128, and 618 lb/acre of phosphorous (P), potassium (K), and calcium (Ca), respectively [Mehlich 1 extract (UGA Agriculture Environmental Services Laboratories, Athens, GA, USA)]. Soil test results from both years indicated a very high and medium supply of P and K, respectively. Feminized seed of day-neutral ‘Pipeline’ and ‘Maverick’ hemp (Kayagene, Hollister, CA, USA) and photoperiod-sensitive ‘Von’ and ‘Whitehouse Cherry’ (Sunbelt Hemp Source, LLC, Moultrie, GA, USA) hemp were sown into 128-cell trays (Speedling, Ruskin, FL, USA) filled with soilless medium (Pro-Mix BX; Premier Tech Horticulture, Quakertown, PA, USA). Seeding was done on 16 and 30 Mar and 14 and 30 Apr 2020 and 2021. ‘Pipeline’ and ‘Maverick’ were available as ‘KG9201’ and ‘KG9202’, respectively, before being named cultivars and are reported in some literature as such (Stack et al. 2019). Seedlings were greenhouse grown with temperature set points of 80/65 °F (day/night). Plants were watered daily as needed and fertilized twice weekly after germination with a 100 $mg \cdot L^{-1}$ nitrogen (N) solution (20N–4.4P–16.6K; Scotts, Marysville, OH, USA).

Plots were chisel plowed and harrowed to a depth of ~8 inches followed by secondary tillage using a tractor-mounted rototiller. After initial tillage and before laying plastic, a preplant homogenized fertilizer consisting of 50 lb/acre N (5.0N–4.4P–12.5K; Athens Seed, Watkinsville, GA, USA) was broadcast applied over plots. Plastic was installed using a raised bed plastic mulch layer (2670; Rain Flo Irrigation, East Earl, PA, USA). Beds were 6 inches tall by 34 inches wide spaced on 6-ft row centers covered with a black on white 1.1-mil-thick total impermeable film plastic mulch [60-inches (Vaporsafe RM; Raven Industries, Sioux Falls, SD, USA)]. The plastic was laid with the black side facing outward. During plastic laying, a single line of drip tubing [12-inch emitter spacing, 0.45 gal/min per 100 ft at 8 psi (T-Tape; Rivulus, Madera, CA, USA)] was placed in the center of the row at a depth of 1–2 inches. An herbicide containing the a.i. 0.7 lb/acre S-metolachlor (Dual Magnum; Syngenta, Greensboro, NC, USA) was applied between rows for weed control. Hand weeding was done within the rows and between rows when needed.

Seedings were ~3 inches tall and were not pinched when transplanted on 9 and 25 Apr and 11 and 28 May 2020 and 2021. Photoperiod-sensitive cultivars, Von and Whitehouse Cherry were planted with an in-row spacing of 36 inches in single rows (2420 plants/acre). The day-neutral cultivars Pipeline and Maverick were planted into a double-row configuration with rows spaced ~18 inches apart on a bed and 16-inch within row spacing (10,890 plants/acre). Plots (experimental units) of the photoperiod-sensitive and day-neutral cultivars contained 8 and 20 plants each, respectively. Adjacent plots within a row were separated by a 9-ft non-planted buffer. A two factorial experimental design using planting date and cultivar was arranged in a randomized complete block design with three replicates in each year. Treatments consisted of the four planting dates (9 and 25 Apr, 11 and 28 May) and four cultivars (Pipeline, Maverick, Von, Whitehouse Cherry).

Plants were fertilized through drip irrigation with 10 lb/acre N (20N–4.4P–16.6K, Scotts) about every 10 to 14 d beginning 2 weeks after the initial planting. Fertilization events were staggered such that day-neutral cultivars received a total of 80 lb/acre N for the season, and photoperiod-sensitive cultivars received 120 lb/acre N. Fertilization amounts were based on current recommendations of 100 to 120 lb/acre N for photoperiod-sensitive industrial hemp in the piedmont region of Georgia, USA (UGA 2020). Once established, plants were irrigated with ~0.5 inch of water weekly through drip irrigation (Coolong 2020). Air temperatures and rainfall were monitored and recorded every 15 min by an on-farm weather station from The University of Georgia Weather Network [UGA Horticulture Station, Watkinsville, GA, USA (UGA 2022)] and irrigation adjusted accordingly. To compare crop development among treatments, growing degree days (GDD°C) after transplanting were estimated by calculating the daily average temperature and subtracting the minimum base temperature of 2.5 °C (Van Der Werf et al. 1995). Prior research suggests that the base temperature for hemp growth in the field is 2.5 °C, while the base temperature for leaf appearance is 1.0 °C. Hemp plants were evaluated weekly starting ~3 weeks after planting for the presence of flowers. Harvests were based on consultations with seed suppliers and when trichome secretions from the flowers turned translucent. In 2020, day-neutral cultivars (Pipeline and Maverick) were harvested at 73, 69, 65, and 48 d after planting for 9 and 25 Apr and 11 and 28 May planting dates, respectively (Table 1). The 11 and 28 May planting dates were harvested on the same day (15 Jul) because of poor growth for the 28 May planting. In 2021, day-neutral cultivars were harvested at 71, 66, 62, and 59 d after planting for the 9 and 25 Apr and 11 and 28 May planting dates, respectively. In 2020 and 2021, the photoperiod-sensitive cultivars (Von and Whitehouse Cherry) were harvested on 18 Sep, which corresponded to 162, 143, 130, and 113 d after planting for 9 and 25 Apr and 11 and 28 May planting dates, respectively.

Immediately before harvest, ~200 g (fresh weight) of flower tissue taken from the apical terminal flower bud was sampled from 5 and 10 plants from each plot of the photoperiod-sensitive and day-neutral cultivars, respectively. Flower material was spread evenly on a perforated baking sheet and dried to ~15% moisture content in a walk-in cooler with a temperature set point of 60 °F and 60% relative humidity. The appropriate relative humidity was maintained using a dehumidifier. After 7 d, flower material was sealed in a metalized resealable food bag (Uline, Braselton, GA, USA) and stored at 0 °C for cannabinoid analysis. For biomass estimation, 5 and 20 entire plants for the photoperiod-sensitive and day-neutral cultivars, respectively, were cut at the soil line and removed from the field. Plants were inverted and hung from wires suspended in an open-air barn and allowed to passively dry to 15% to 25% moisture content for ~14 d. The dry plants were then hand stripped of flowers and remaining leaf tissue. Stripped flower and leaf material were weighed and sampled (200 g) to determine the moisture content. Moisture content for each sample was determined using a forced air oven with a set point of 65 °C to a constant weight. Flower biomass (yield) values were then normalized for a moisture content of 10%.

The acidic and neutral (decarboxylated) forms of the cannabinoids, THC, CBD, CBG, and cannibichromene (CBC), were determined according to Storm et al. (2020) by a commercial laboratory (SJ Laboratories & Analytics, Macon, GA, USA). In brief, a 200-mg sample of homogenized dried flower material was extracted with 20 mL of methanol in a 50-mL centrifuge tube. Tubes were shaken on a vortex mixer for 10 min, centrifuged at 4100 g_n for 5 min, and a 50-µL aliquot of supernatant was diluted with 950 µL of methanol and filtered through a 0.45-µm regenerated cellulose syringe filter (4 mm Captiva; Agilent, Santa Clara, CA, USA). Analysis was done using high-performance liquid chromatography (1220 Infinity II LC; Agilent) with a variable wavelength diode array detector (Agilent). Ten microliters of the methanol extract was injected into a 3.0 × 50-mm, 2.7-µm column liquid chromatography column (Infinity Laboratory Poroshell 120 EC-C18; Agilent). The flow rate was set at 1.0 mL·min^{-1} for the duration of the run and eluents were A) 0.1% aqueous formic acid, B) 0.1% formic acid in methanol. A gradient run was programmed as follows: 40% A and 60% B for 1.0 min, 40% to 23% A and 60% to 77% B for the next 7.0 min, then 5% A and 95% B for the final 2.0 min. The column was returned to the initial 40% A and 60% B over the next 1.0 min. Compounds were detected on a diode array detector set to 230 nm. Total cannabinoid concentrations were calculated with the following formula: neutral form + (acidic form × 0.877). Percentage dry matter for all samples was recorded and results reported on a dry weight basis.

Data were analyzed using the GLM procedure as implemented in SAS PROC GLM (version 9.4; SAS Institute Inc., Cary, NC, USA). Because day-neutral and photoperiod-sensitive plants were grown with different spacing, they were analyzed separately for evaluating the impact of planting date on total yield. Yields and cannabinoid data were analyzed for the presence of significant main effects and interactions ($P < 0.05$) using planting period, cultivar, and year as fixed effects. When interactions were not present, data main effects were analyzed. Least-square means comparisons were performed using the Fisher's least significant difference test ($P < 0.05$).

Table 1. Planting and harvest dates for day-neutral ('Pipeline' and 'Maverick') and photoperiod-sensitive ('Von' and 'Whitehouse Cherry') hemp (*Cannabis sativa*) grown in Watkinsville, GA, USA, in 2020 and 2021.

	2020		2021	
	Day-neutral	Photoperiod-sensitive	Day-neutral	Photoperiod-sensitive
Planting date	Harvest date			
9 Apr	24 Jun	18 Sep	21 Jun	18 Sep
25 Apr	3 Jul	18 Sep	30 Jun	18 Sep
11 May	15 Jul	18 Sep	12 Jul	18 Sep
28 May	15 Jul	18 Sep	26 Jul	18 Sep

Results and discussion

The average air temperature for both 2020 and 2021 growing seasons was 22.4 °C (data not shown). During the planting period there were considerable temperature fluctuations, as is typical for the region (Fig. 1). In 2021, there were several days when air temperatures after the third (11 May) planting date were consistently above 30 °C. This contrasted with 2020, when maximum daily air temperatures during the planting period reached 30 °C only once (Fig. 1). However, in mid-Jul 2020, during harvest of day-neutral cultivars, high temperatures exceeded 35 °C for several days. Total rainfall in 2020 and 2021 growing seasons was 687 and 579 mm, respectively. Although the 2020 growing season received 108 mm more rainfall than 2021, a large rain event (Fig. 1), occurring 17 and 18 Sep, accounted for much of this difference.

For day-neutral cultivars, Maverick and Pipeline, flower initiation was visually detectable ~5 weeks before harvest for all but one planting date (Table 2). This was later than reported in trials conducted in Louisiana and New York,

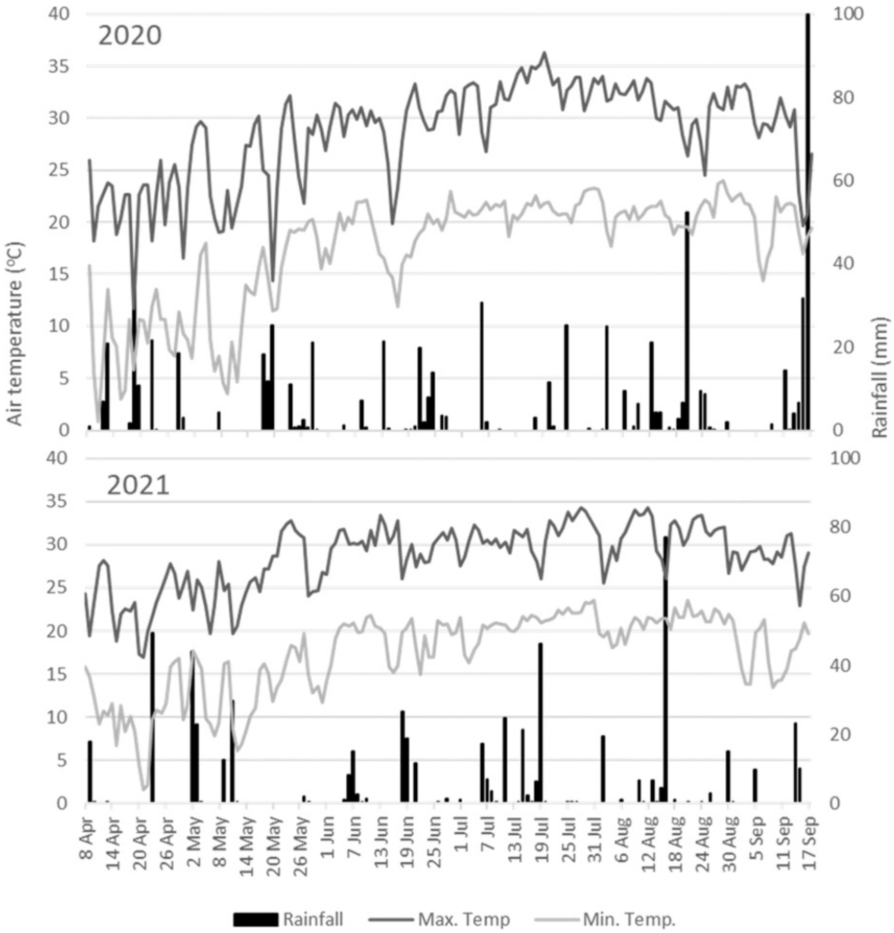

Fig. 1. Average daily maximum (Max.) and minimum (Min.) air temperatures and accumulated rainfall at the study location for hemp (*Cannabis sativa*) grown in Watkinsville, GA, USA, in 2020 and 2021; (°C × 1.8) + 32 = °F, 1 mm = 0.0394 inch.

where both cultivars began flowering within 2 weeks of transplanting (Deynzer 2022; Stack et al. 2019). In 2020 and 2021, day-neutral cultivars were harvested between 48 to 73 d after planting (Table 1). In 2020, flowering was observed between 534 and 742 GDD°C. At harvest, GDD°C ranged from 1059 to 1300 GDD°C for 'Pipeline' and 'Maverick'. The final planting date (28 May) in 2020 was harvested earlier than expected (15 Jul), due to premature flowering after planting (Table 2). In 2021, flowering was initiated in day-neutral cultivars between 754 and 773 GDD°C, and harvest occurred between 1273 to 1293 GDD°C. The GDD°C from planting to flowering in the present study for the day-neutral cultivars were similar to those reported for hemp selected to grow under short (11.5 h) daylengths in subtropical locations (De Prato et al. 2022). The day-neutral trait is prevalent in hemp that is selected for extreme northern latitudes, where cold weather is coupled with short growing seasons, or near the equator, where daylength remains consistent throughout the year (Small 2015). Temperature has been reported to affect flowering time significantly in some tropical hemp cultivars selected to grow under short daylengths (De Prato et al. 2022).

Flower initiation was visible in photoperiod-sensitive cultivars the week of 10 Aug, regardless of planting date in 2020 and 2021. Due to similar flowering patterns, photoperiod-sensitive cultivars were harvested on the same day (18 Sep) (Table 1). Flower initials were observed between 2405 to 1680 GDD°C for the earliest and latest planting dates, respectively, in 2020. In 2021, flower initiation was observed between 2408 to 1634 GDD°C for the earliest and latest planting dates, respectively. Air temperatures were similar in both growing seasons, resulting in comparable GDD°C accumulation at flowering. At harvest, GDD°C for the photoperiod-sensitive cultivars varied by more 700 GDD°C between first and last planting dates. This is expected, as flowering in these cultivars is primarily determined by photoperiod once the juvenile growth period has been completed. The cumulative GDD°C from planting until flowering in the present study were within the ranges previously reported for photoperiod-sensitive fiber hemp cultivars (Amaducci et al. 2008b). Seedlings of photoperiod-sensitive cultivars in this study grew vegetatively in April and early May, despite being planted during photoperiods that were conducive to floral initiation. This

Table 2. Celsius degree days (GDD°C) from planting until flowering (Flower) and planting until harvest (Harvest) for day-neutral ('Pipeline' and 'Maverick') and photoperiod-sensitive ('Von' and 'Whitehouse Cherry') hemp (*Cannabis sativa*) planted on four dates and grown in 2020 and 2021 in Watkinsville, GA, USA.

	2020				2021			
	Day-neutral		Photoperiod-sensitive		Day-neutral		Photoperiod-sensitive	
	Flower	Harvest	Flower	Harvest	Flower	Harvest	Flower	Harvest
Planting date	(GDD°C)[i]							
9 Apr	742	1300	2405	3253	773	1293	2408	3246
25 Apr	724	1296	2198	3047	754	1273	2195	3034
11 May	735	1344	1966	2816	758	1274	1936	2809
28 May	534	1059	1680	2530	756	1291	1634	2473

[i] GDD°C = Σ(average daily temperature – 2.5 °C), (°C × 1.8) + 32 = °F.

suggests that during this period, 'Von' and 'Whitehouse Cherry' may have been in a juvenile growth phase. Lisson et al. (2000) reported that the duration of the juvenile phase in two hemp cultivars ranged from 383 to 390 GDD°C using a base temperature of 1 °C. Plants that were placed in the field on 9 Apr reached ~400 GDD°C during the first week of May in both study years (data not shown). By mid-May, daylengths in the study location began to exceed 13.5 h. Plants used in the present study were grown from seed and not rooted cuttings. Hemp nursery stock, which is typically the source for rooted cuttings, may complete developmental requirements of the juvenile phase when planted (Lisson et al. 2000). Empirical observations by the authors using rooted cuttings of hemp suggest that vegetatively propagated plants may have initiated flowering if planted during early April in the same location (data not shown).

Due to differences in growth habit and production practices, the day-neutral cultivars, Pipeline and Maverick, were analyzed separately for yield from the photoperiod-sensitive cultivars. For 'Pipeline' and 'Maverick' there was a significant year by cultivar by planting date interaction for flower yield (Fig. 2). In 2020, yields for 'Maverick' and 'Pipeline' decreased as planting date progressed from 9 Apr to 28 May. Yields for the 9 Apr planting of Maverick averaged 1890 lb/acre, decreasing to 187 lb/acre for the 28 May planting. Similarly, yields of 'Pipeline' were 1112 and 1243 lb/acre for the 9 and 25 Apr planting dates, respectively, and decreased to 71 lb/acre for the 28 May planting. In 2020 'Maverick' yielded more than 'Pipeline' for all but the 28 May planting date. In 2021 'Maverick' yields were greater than 'Pipeline' for the 9 and 25 Apr and 28 May planting dates (Fig. 2). In 2021, yields for 'Pipeline' were lower for the last three planting dates compared with 9 Apr. 'Maverick' has been previously reported to yield more than 'Pipeline' in field trials in New York and Florida (Stack et al. 2019; Yang et al. 2020). The yields for the day-neutral cultivars in the present study were slightly greater than those obtained in Florida (Yang et al. 2020) and similar to those obtained in New York (Stack et al. 2019). In 2021, yields of 'Maverick' decreased significantly for the 11 May planting date compared with the others. This may be because of a period of temperatures exceeding 32 °C that occurred shortly after planting, which may have negatively affected growth and yields. Previous studies reported improved growth of hemp at 15 °C compared with 30 °C (Nelson 1944). If the day-neutral trait in 'Pipeline' and 'Maverick' evolved from plants selected from higher latitudes (Zhang et al. 2018), it is possible that these cultivars may be better suited to cooler growing conditions. Further, observations of commercial production of 'Pipeline' and 'Maverick' suggests that they produce more biomass under cooler air temperatures (Czaplewski S, personal communication).

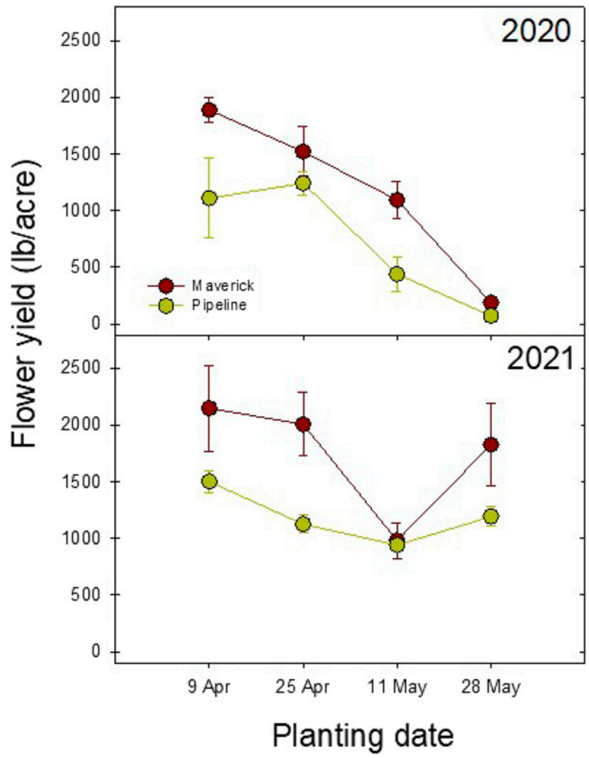

Fig. 2. Mean flower yield (± *SE*) for 'Maverick' and 'Pipeline' hemp (*Cannabis sativa*) planted on four dates and in Watkinsville, GA, USA, in 2020 and 2021; 1 lb/acre = 1.1209 kg·ha^{-1}.

There was a significant year by cultivar interaction for flower yield of the photoperiod-sensitive cultivars (Fig. 3). In 2020, there was no difference in floral yield between the photoperiod-sensitive cultivars. In 2021, 'Von' had a significantly greater yield than 'Whitehouse Cherry'. In 2020, the average floral yield for 'Von' and 'Whitehouse Cherry' was 1536 lb/acre (data not shown). In 2021, 'Whitehouse Cherry' yielded 2185 lb/acre of flower biomass, while 'Von' produced 3755 lb/acre of biomass (Fig. 3). Although average temperatures were the same for both seasons and rainfall amounts similar, there was less daily variation in air temperatures in 2021 and fewer rain events during flower development, which may have led to increased yields (Fig. 1).

Planting date did not affect floral yield of the photoperiod-sensitive cultivars Von or Whitehouse Cherry (P = 0.096). Prior research has typically focused on the impact of environment on stem biomass for hemp grown for fiber, with longer vegetative periods corresponding to increased stem yields (Tang et al. 2016). Recently, Linder et al. (2022) reported a linear decrease in yield of a photoperiod-sensitive hemp cultivar as planting progressed from 11 May and 7 Jul in North Carolina. Although plant canopy size was not quantified in the present study, 'Von' and 'Whitehouse Cherry' planted on 9 Apr were larger in appearance than those planted in May. However, the visual increase in plant canopy did not correspond to increases in flower biomass. Linder et al. (2022) reported significant increases in height and width of 'BaOx' plants when planted in May compared with June and July. In that study, the increased plant size corresponded to increased floral yields. It should be noted that the earliest planting

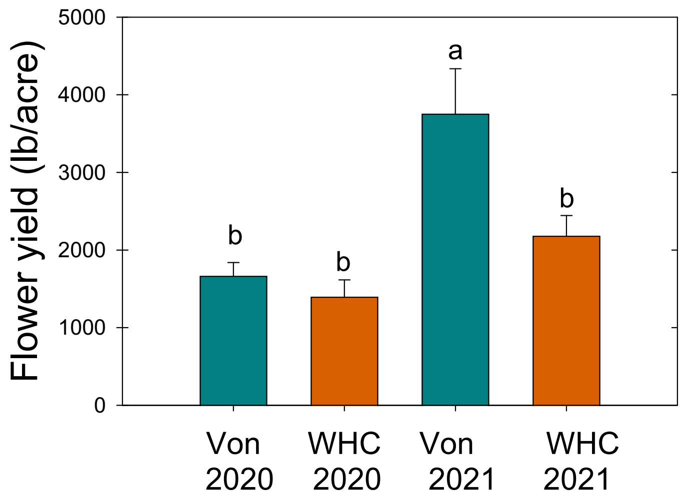

Fig. 3. Mean flower yield (± *SE*) for 'Von' and 'Whitehouse Cherry' (WHC) hemp (*Cannabis sativa*) grown in Watkinsville, GA, USA, in 2020 and 2021. Bars associated with the same letter(s) are not significantly different at $P \leq 0.05$ according to Fisher's least significant difference test; 1 lb/acre =1.1209 kg·ha^{-1}.

in the present study occurred ~1 month earlier than in the North Carolina trial (Linder et al. 2022). The cooler growing conditions during the earlier planting period in the present study may have resulted in smaller differences in total plant growth among the different planting dates compared with the North Carolina study. Visible flower initiation in 'Von' and 'Whitehouse Cherry' occurred in early August for all planting dates.

Although directly comparing flower yields of day-neutral and photoperiod-sensitive cultivars was not a primary objective of this study, average flower yields per acre and per plant were greater for photoperiod-sensitive cultivars compared with the day-neutral types. Average flower yields were 2221 and 1202 lb/acre for the photoperiod-sensitive and day-neutral cultivars, respectively (Fig. 4A). Further, flower yields were 0.98 and 0.11 lb/plant for the photoperiod-sensitive and day-neutral cultivars, respectively (Fig. 4B). Despite a nearly 10-fold difference in per-plant yields, the increased planting density of the day-neutral cultivars resulted in smaller relative differences in total flower yields per acre between the two hemp types.

Total THC concentrations in flower material were unaffected by any treatment interaction, planting date, cultivar, or study year (Table 3). At harvest, all cultivars and planting dates had total THC concentrations that exceeded the 0.3% US threshold for industrial hemp (USDA 2019). It is not uncommon for high CBD hemp cultivars to have THC concentrations exceeding the 0.3% threshold (Stack et al. 2019; Yang et al. 2020). The day-neutral cultivars, Pipeline and Maverick, exhibited total THC concentrations that were higher than previously reported for these plants at harvest (Stack et al. 2019; Yang et al. 2020). Yang et al. (2020) reported total THC levels of 0.286% and 0.314% for 'Pipeline' and 'Maverick', respectively, at harvest. Concentrations in the present study averaged 0.456% and 0.395% for 'Pipeline' and 'Maverick', respectively. In the current study, flowering in 'Pipeline' and 'Maverick' was initiated 3 to 4 weeks after transplanting and continued for ~4 to 5 weeks until harvest for most planting dates. In Yang et al. (2020), total THC levels in 'Pipeline' and 'Maverick' peaked at ~6 weeks after flower initiation at concentrations between 0.5% and 0.6% and then declined until harvest at 9 weeks after floral initiation. Therefore, although concentrations of total THC at harvest differed from Yang et al. (2020), the concentrations of total THC for 'Pipeline' and 'Maverick' were comparable at the same stage of floral development. Total THC concentrations at harvest for 'Von' and 'Whitehouse Cherry' were 0.488% and 0.495%, respectively.

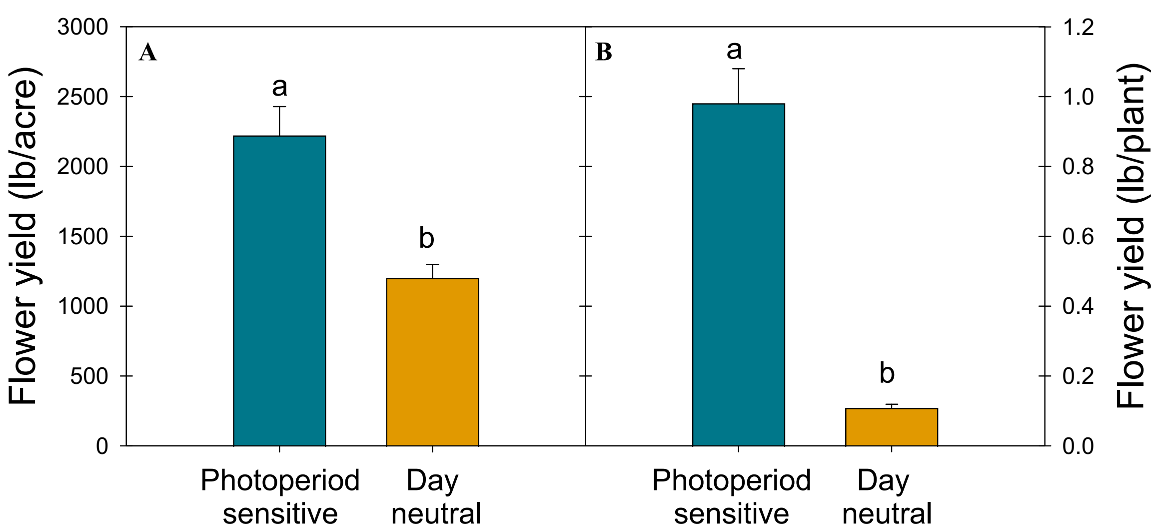

Fig. 4. Mean flower yield (± *SE*) per acre (A) and per plant (B) for day-neutral ('Pipeline' and 'Maverick') and photoperiod-sensitive ('Von' and 'Whitehouse Cherry') hemp (*Cannabis sativa*) grown in Watkinsville, GA, USA, in 2020 and 2021. Bars associated with the same letter(s) are not significantly different at $P \leq 0.05$ according to Fisher's least significant difference test; 1 lb/acre =1.1209 kg·ha^{-1}, 1 lb = 0.4536 kg.

Table 3. Concentrations of total tetrahydrocannabinol (THC), cannabidiol (CBD), cannabigerol (CBG), and cannabichromene (CBC) in flower material 'Pipeline', 'Maverick', 'Von', and 'Whitehouse Cherry' hemp (*Cannabis sativa*) grown in Watkinsville, GA, USA in 2020 and 2021.

	Concn in flowers (% dry wt)			
	Total THC	Total CBD	Total CBG	Total CBC
Cultivar				
Pipeline	0.456	6.463 c[i]	0.137 c	0.254 b
Maverick	0.395	9.287 b	0.299 a	0.611 a
Von	0.488	10.494 a	0.203 b	0.607 a
Whitehouse Cherry	0.495	10.082 ab	0.197 bc	0.623 a
Year				
2020	0.465	10.146 a	0.360 a	0.548 a
2021	0.452	8.094 b	0.063 b	0.506 a

[i] Values within the same column and treatment group followed by the same letter(s) are not significantly different at $P \leq 0.05$ according to Fisher's least significant difference test.

Although these are above the 0.3% USDA threshold, they are within previously reported ranges for other photoperiod-sensitive cultivars (Stack et al. 2019).

Total CBD concentrations in the floral material were unaffected by any treatment interactions. However, total CBD concentrations were affected by the main effects of cultivar and year (Table 3). Total CBD concentrations were 10.494% and 10.082% in 'Von' and 'Whitehouse Cherry', respectively. Concentrations of CBD were lowest in the day-neutral cultivar Pipeline (6.463%). 'Maverick' (9.287%) had higher CBD concentrations than 'Pipeline' but was not different from the two photoperiod-sensitive cultivars. Total CBD concentrations in floral tissue of 'Pipeline' and 'Maverick' were slightly higher than previously reported (Yang et al. 2020). Total CBD concentrations averaged across all cultivars were affected by growing season, decreasing in 2021 (8.094%) compared with 2020 (10.146%). Although variation in cannabinoid concentrations is affected by genetics, it is also understood that there are genetic by environment interactions that may affect cannabinoid concentrations (Trancoso et al. 2022).

Concentrations of total CBG were also affected by cultivar and year. Although present in relatively small quantities compared with CBD, CBG is of interest for many hemp growers. Concentrations of CBG were highest in 'Maverick' (0.299%), and lowest in 'Whitehouse Cherry' (0.197%) and 'Pipeline' (0.137%). None of the cultivars used in this study have been selected for CBG production and it is expected that overall concentrations would be lower than other cannabinoids. Cannibichromene is another minor cannabinoid that is found in hemp. Although less well known than CBD or CBG, there is an interest in production of CBC for therapeutic reasons (Morales et al. 2017). Concentrations of total CBC were affected by cultivar, but not year. The day-neutral cultivar Pipeline (0.254%) had significantly lower concentrations of CBC than the other cultivars (0.607% to 0.623%) grown in this trial.

Conclusions

The impact of planting date on floral yield in photoperiod-sensitive hemp was recently investigated (Linder et al. 2022); however, the effects of planting date of day-neutral and photoperiod-sensitive hemp cultivars planted before the critical photoperiod has not been previously evaluated. Flower yields of the day-neutral cultivars decreased as planting date progressed during the year and temperatures warmed. In the present study, photoperiod-sensitive cultivars (Von and Whitehouse Cherry) did not initiate flowering despite being planted at a time when daylength would induce flowering. Although photoperiod-sensitive hemp exhibited greater floral yields than day-neutral hemp cultivars, our findings suggest that the day-neutral cultivars would allow growers in parts of the southeastern United States to take advantage of mild spring weather to extend their production season for hemp.

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