Article

Performance of Different-Use Type Industrial Hemp Cultivars under Mid-Atlantic Region Conditions

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Abstract: Due to recent classification as a commodity crop in North America, producer interest in industrial hemp (*Cannabis sativa* L.) has increased. In the Commonwealth of Virginia, there is a need to evaluate foreign-developed industrial hemp for its adaptability and to develop new cultivars suited to local climatic conditions. Eight cultivars ('Bialobrzieskie', 'Canda', 'Fedora 17', 'Felina 32', 'Joey', 'Tygra', 'USO 31', and 'Wojko') were evaluated for grain and five ('Bialobrzieskie', 'Carmagnola', 'Fedora 17', 'Futura 75', and 'Wojko') for vegetative biomass. An experiment carried out at the Virginia State Research and Demonstration (Randolph) farm was laid out in a randomized complete block design with three replications. The results show that cultivars differed in the cumulative growing degree days (CGDD) needed for growth phase transitions, with 'USO 31' having an early transition to the reproductive phase. In addition, 'Fedora 17' produced greater grain yield and may have the potential for greater performance with better management to improve its adaptability to local conditions. Across cultivars and years, the grain protein content averaged 241 g kg⁻¹ and the mineral elements were at sufficient levels for animal and human nutrition. 'Carmagnola' produced greater biomass yield and has the potential for adoption as local fiber cultivar.

Keywords: *Cannabis sativa* L.; planting date; yield; biomass; fiber; CGDD

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1. Introduction

Industrial hemp belongs to the Cannabaceae family, and while three species: *C. sativa*, *C. indica*, and *C. ruderalis* have been previously proposed [1], *C. sativa* has recently been recommended as the only recognized species [2,3]. The plants produce a unique group of compounds collectively called cannabinoids. Its cultivars can be classified based on their chemical profile, a genetic presence of alleles for contrasting cannabinoids, the psychoactive compound Delta-9-tetrahydrocannabinol (THC), and cannabidiol (CBD) [4]. Marijuana contains 3–15% THC by weight, while industrial hemp and other fiber and oil-seed *Cannabis* generally contain less than 1% THC and high CBD content. Hemp is naturally dioecious [5], but monoecious hemp has been introduced and is found spontaneously at a very low frequency (0.1%) in dioecious hemp farms [6]. All *Cannabis* are interfertile, and no known sexual incompatibility has been reported [7].

A uniform phenological coding system for hemp is important for efficient planning and design of crop management strategies [8]. A noncomprehensive decimal code introduced by Mediavilla et al. [9] divides the hemp life cycle into four principal stages: germination and emergence, vegetative growth, flowering, and seed formation and senescence, each with secondary stages. Later a BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) coding system was introduced for hemp by Mishchenko et al. [8] based on the general BBCH scale, a standard coding system used to identify plants' phenological development stages [10–12]. Based on Mishchenko et al. [8], the hemp life cycle is divided into nine principal growth stages, including germination and sprouting (0), leaf development (1), the formation of lateral shoots (2), stem elongation (3), inflorescence

emergence (5), flowering (6), development of fruit (7), ripening of fruit (8), and senescence (9). Each stage is subdivided into secondary stages based on its main distinctive features [8]. Prediction of plant growth stages is possible by use of growing degree days (GDD) [13]. The calculation of cumulative growing degree days (CGDD) using a biological temperature minimum (a value which indicates the beginning or end of growth) is essential in the plants' life and helps to estimate the range time of each growth stage in hemp [14]. Bócsa and Karus [1] stated that the GDD requirement is variety dependent. Fiber-hemp plants require 1900–2000 GDD from germination to technical maturity (110–115 days) and seed-hemp plants require 2700–3000 GDD until seed maturity.

Most hemp cultivars are adapted to temperate or equatorial climate [15], distributed between 25 and 55 degree parallels on either side of the equator [16], and require around 250–300 mm precipitation that is well distributed during the growing season [17]. Hemp germinates at soil temperatures of 8–10 °C and within 8–12 days of planting [17]. Hemp is a very photosensitive plant and flowering is triggered by shortening day length [18] and delayed by long days [19]. The critical day length is longer for male plants than for female plants of the same cultivar [20]. Because flowering depends on cumulative degree days since planting and cultivar's photoperiodic behavior and sensitivity, differences in cultivar sensitivity to light could impact crop yield [21]. Planting too early in spring results in low and poor germination and emergence while late sowing reduces the plant growth period and quality and quantity of yields [17]. After the implantation phase, and when active growth starts, the temperature sum accumulation starts to influence yield [21] and depending on intended use, crop harvest timing can impact yield and quality of hemp products. For fiber, harvest should be carried out during male flowering or during the flowering for monoecious crops. For essential oil, one to three weeks before seed maturity, and for cannabinoids extraction, inflorescences are harvested at the beginning of seed maturity [9].

Hemp has been proposed as a plant that mitigates climate change, because of its similarity to fast-growing hardwoods [22]. It removes carbon dioxide (CO₂) via photosynthesis, thus enhancing its potential as a terrestrial carbon sink, and biomass generated finds multiple uses as fiber for textiles and paper industry and manufacture of building materials. The high cellulose content and its physiology make it an ideal alternative to the starch-based crops as feedstock for ethanol [23]. Hemp plant is better at extracting heavy metals from the soil than many agricultural crops [24–27] and could be an environmentally sound and viable feedstock. When used in rotation cropping, dead hemp roots improve soil structure and are reported to increase yield in the crop following hemp [28]. Industrial hemp yields of up to 785 kg ha^{−1} grain, 468 L ha^{−1} oil, 594 kg ha^{−1} meal, 5941 kg ha^{−1} straw, or 1457 kg ha^{−1} fiber have been reported in Canada [29]. Hemp seed is a good source of oil (50%), 90% of which is unsaturated in some Chinese cultivars [30]. Different cultivars vary in their seed content of gamma-linolenic acid (GLA) and omega-6 to omega-3 ratio [31] and anti-nutrition attributes like phytic acid levels [32]. Hemp polyunsaturated fatty acid contents, and stability against oxidation, make hemp oil good for the cosmetic industry [33]. Hemp seed contains high-quality storage proteins rich in all essential amino acids and especially arginine, has high, easily digestible fiber, and is gluten-free [34]. The left-over cake from grain oil extraction can be used to substitute soybean and other high protein cakes as livestock feed supplement [34,35]. A laying chicken fed a diet containing hemp seed or oil produced eggs with increased omega-3 fatty acids contents [36]. Other studies report hemp seed to be rich in iron, manganese, and zinc—critical elements in human and animal health [27]. Therefore, there is a need to determine performance in Virginia of grain cultivars with high protein and oil content, reduced anti-nutrient qualities, and high micronutrient element contents for use in animal and human food supplements and other industrial products.

In spite of hemp production prohibition in the US, the annual sale in North America of hemp-based products, derived predominantly from imported material, was approximately \$400 million [37]. It is reported that the combined US income from hemp seed for food and

pharmaceutical products alone amounted to 40.5 million dollars in 2012 [38]. The estimates from Vote Hemp (a nonprofit organization which works on hemp in the U.S.) show that the total retail value of hemp products (food and body products, clothing, auto parts, building materials, and other products) in the U.S. In 2017 was increased to \$820 million [39]. Because these sales are met with imports, there is a need to promote locally produced hemp to meet local market demands and the production of industrial hemp has the potential to positively impact the US economy. While hemp cultivar development and production continued elsewhere in the world, the long period of legal prohibition in the United States has led to low availability of local genetic materials [40]. Subsequently, even as legislative action in recent years removed the legal prohibition and made hemp a commodity crop, there exist challenges to its production due to the low availability of adapted genetic materials. However, the removal of prohibition allowed for the establishment of this project to evaluate foreign bred hemp cultivars for their adaptability and productivity potentials in the mid-central part of the Commonwealth of Virginia.

2. Materials and Methods

2.1. Experimental Site, Propagating Material, and Planting Dates

The research was carried out in 2017 and 2019 at the Research and Demonstration Farm, Virginia State University (VSU) in Chesterfield County, Virginia, USA (latitude 37° 13' N, longitude 77° 26' W, elevation 30 m). The land is gently sloped (1–4%), and the soil type is Bourne series fine sandy loam (mixed, semi-active, thermic Typic Fragiudults) with a low organic matter content. Prior to establishing the experiment, a composite topsoil sample was obtained for chemical analysis. The weather conditions during the production years are summarized in Figure 1.

Figure 1. Weather history (average temperature, total precipitation, and day length), Petersburg, Virginia, 2017 and 2019 [41].

Seeds of industrial hemp cultivars were obtained from two sources: (i) Hempoint company (Czech Republic) and (ii) Parklands Industrial Hemp Growers (Canada). Ten cultivars of hemp in three use categories (Biomass, Seed/biomass (Dual), and grain-type) as indicated by the seed suppliers were planted on 14 April, 3 May, 17 May, 1 June, and 14 June in 2017 and on 28 April, 9 May, and 28 May in 2019. The differences in planting date between the production years was a result of weather conditions, which determined field access. June planting was omitted in 2019 due to a crop planted after June 1 in 2017 transitioning to reproductive phase after a short vegetative growth because of the crop photoperiod sensitivity. Cultivars used in the study and their characteristics like origin,

gender, and usage purpose, as indicated by several breeders/companies, are illustrated in Table 1.

Table 1. Some characteristics of industrial hemp cultivars planted at the Research and Demonstration Farm, Virginia State University.

Cultivars	Origin	Sexual type	Usage *
Bialobrzeskie	Poland ^a	Monoecious ^b	Fiber ^b
Canda	Canada ^a	Monoecious ^c	Grain/Fiber ^c
Carmagnola	Italy ^a	Dioecious ^d	Fiber/CBD ^d
Fedora 17	France ^a	Monoecious ^b	Grain/CBD ^{b,c}
Felina 32	France ^a	Monoecious ^b	Grain/CBD ^{b,c}
Futura 75	France ^a	Monoecious ^b	Grain/Fiber/CBD ^{b,c}
Joey	Canada ^a	Monoecious ^c	Grain/Fiber ^c
Tygra	Poland ^a	Monoecious ^e	Grain/Fiber ^e
USO 31	Ukraine ^a	Monoecious ^b	Grain ^b
Wojko	Poland ^a	Monoecious ^d	Grain/Fiber ^f

^a [42]; ^b [43]; ^c [44]; ^d [45]; ^e [17]; ^f [46]. * Grain (seed); Fiber (hurd); CBD (flower).

2.2. Experimental Design

The study was two-factor (cultivars and planting date) and treatments were applied in a split plot design with planting date as main plot and cultivars as sub-plot. Grain- and fiber-type hemp cultivars were studied independently. Some of the dual use cultivars were evaluated for both grain and biomass. Each 1.6 × 3.7 m experimental unit was planted with four rows 38 cm apart for grain and eight rows 19 cm apart for fiber. Planting was done with a drill planter at a depth of 1–2 cm and a seeding rate of 60 kg ha^{−1} dual (fiber/seed) types and 30 kg ha^{−1} for seed-type cultivars. Phosphorus (0-45-0) and potassium (0-0-60) fertilizers were applied at planting time based on soil samples analysis and recommendation for corn by the Virginia Tech Soil Laboratory. Nitrogen was applied by hand post emergence (approximately 20 cm height) at 200 and 80 kg N ha^{−1} for grain and fiber cultivars, respectively. A pre-emergent glyphosate was used for weed control and post-emergent tilling was done where needed.

2.3. Field Data Acquisition

2.3.1. Cumulative Growing Degree Day

Five grain-type cultivars ('Canda', 'Joey', 'Felina 32', 'USO 31', and 'Bialobrzeskie'), two fiber-type cultivars ('Carmagnola', and 'Futura 75'), and one dual cultivar ('Fedora 17') were evaluated in three replicates in the summer of 2019 to find the relation of phenological growth stages and the cumulative growing degree days (CGDD). Data were recorded in 2 × 1 feet sampling plants within each replicate. The Biologische Bundesanstalt, BUNDessortenamt und Chemische Industrie (BBCH) coding method was used to record phenological data, and the CGDD was calculated from planting time based on the Karow et al., method (2013):

$$CGDD = \sum_{i=1}^n (T_a - T_b) \quad (1)$$

where, n = number of days from the planting date as the biofix (a biological event or indicator of the developmental event) to the date of occurrence of each phenological stage, T_a = average daily temperature, and T_b = is the base temperature (1 °C).

2.3.2. Plant Density, Vegetative Productivity, and Height at Harvest

Plant density was obtained 3–4 weeks after emergence by counting number of plants on 1.2 m representative section in one of the middle rows. Vegetative biomass production, a measure of plant growth vigor, was obtained for fiber-type cultivars. At the time of biomass harvest during late flowering, two 1.0 m² areas were randomly selected in each plot, mean plant heights obtained, and all plants in the selected area harvested. The harvested material was dried in a Grieve forced-air oven (The Grieve Corporation, Round Lake, IL, USA) at

65 °C for least 96 h or until a constant dry weight and dry biomass determined. The dried stems were then ground and analyzed for elemental composition using AOAC Official Methods by Waypoint Analytics (Leola, PA, USA).

2.3.3. Grain Yield and Composition

After seed maturity, two 1.0 m² representative areas of the plot were selected, plant height taken, and all material harvested and bagged. The materials were allowed to dry in a Grieve forced-air oven at 65 °C for 48 h and seed threshed and shelled using a Haldrup LT-35 stationary thresher (Haldrup, Ilsofen, Germany). The weight of the seeds was determined and stored in a cooler at 5 °C till it was ready for analysis. A sample of the seed was obtained, ground, and analyzed for oil, protein, and mineral element content. Analysis was done using AOAC Official Methods by Waypoint Analytics (Leola, PA, USA).

2.4. Data Analysis

Data processing and analysis of variance (ANOVA) was performed using statistical software (PROC GLM (SAS version 9.4; SAS Institute, Cary, NC, USA)) [47]. Data for each year were analyzed and reported independently with cultivar and planting date as fixed effects and replications as a random effect. Because interaction between cultivar and planting dates when present was only in very few parameters, and even when so, not very strong, only main factor effects are reported.

3. Results

3.1. Soil Characteristics and Weather Condition at the Site

Detailed chemical characteristics of the soil at the site are given in Table 2. The weather condition is summarized in Figure 1, showing relatively warmer and drier conditions in 2019 compared to 2017. The average temperature was generally close in both years in June and July, but in the early season (April and May), and at the end of the season (August and September), they were higher in 2019 than in 2017. While precipitation amount in June and July of 2019 was more than in 2017, the total precipitation in the growing season was less than in 2017 (Figure 1). In 2017, the total precipitation amount received by plots differed because planting date was spread over a 45-day period (14 April till 1 June).

Table 2. Soil analysis in 2017 and 2019 of industrial hemp fields in Randolph Farm Station, Petersburg, Virginia.

Soil Analysis	2017	2019
pH	5.7	5.7
P (kg ha ^{−1})	119	156
K (kg ha ^{−1})	179	165
Ca (kg ha ^{−1})	599	587
Mg (kg ha ^{−1})	76	75
Zn (mg kg ^{−1})	2	1.4
Mn (mg kg ^{−1})	6.2	12.8
Cu (mg kg ^{−1})	0.9	1
Fe (mg kg ^{−1})	22.4	26.2
B (mg kg ^{−1})	0.1	0.1

3.2. Cumulative Growing Degree Day

Data obtained indicate that there exist differences among industrial hemp cultivars in how their phenological and morphological growth phases are affected by CGDD. While grain-type cultivar like ‘USO 31’ shows an early transition to the reproductive phase (flower primordia formation at stage 51 BBCH) (1079 CGDD), fiber-type cultivar ‘Carmagnola’ had a delayed response (1543 CGDD) (Figure 2).

Figure 2. Industrial hemp (Grain, Fiber, and Dual types) and the relation of Cumulative Growing Degree Days (Base Temp 1 °C—[14]) with growth stages based on BBCH Code 11 (First leaf pair); 12 (Second leaf pair); 13 (Third leaf pair); 14 (Fourth leaf pair); 15 (Fifth leaf pair); 16 (Sixth leaf pair); 17 (Seventh leaf pair); 18 (Eighth leaf pair); 19 (Ninth leaf pair); 39 (Change of phyllotaxis); 51 (Flower primordia); 59 (Pistillate flower formation, formed perigonal bract); 60 (Beginning of flowering-style formed); and 62 (Spike). Seeds were planted on 9 May 2019, and harvested on 16 August 2019 for grain type cultivars except for Felina32, which harvested with fiber type cultivars on 20 August 2019.

3.3. Plant Density and Height at Grain Harvest

Plant density was not affected by cultivar and planting date interaction in 2017. Plant density ranged from 17.7 plants m⁻² in ‘Canda’ to 25.0 plants m⁻² in ‘Felina 32’, and there was no significant difference among cultivars (Table 3). In 2019, a thousand seed weight differed with cultivar from a low of 12.1 g (‘Bialobrzieskie’) and 12.6 g (‘Felina 32’), to a high of 17.5 g (‘Canda’).

Table 3. Comparison of some characteristics of grain hemp cultivars. Values are calculated means of different planting dates.

Cultivars	Plant Density (Plants m ⁻²)		Height at Harvest (cm)		Seed Yield (kg ha ⁻¹)		Thousands Seed Weight (g)	
	2017	2019	2017	2019	2017	2019	2017	2019
Bialobrzieskie		93.7 ^a		89.6 ^{ab}		365.6 ^c		12.1 ^e
Canda	17.7	67.7 ^{bc}	74.7 ^c	82.1 ^{bc}	458.3	525.6 ^b		17.5 ^a
Fedora 17		79.6 ^{ab}		86.4 ^{bc}		770.9 ^a		14.9 ^c
Felina 32	25.0	84.6 ^{ab}	101.3 ^a	100.4 ^a	536.9	434.2 ^{bc}		12.6 ^{de}
Joey		58.8 ^c		76.4 ^c		540.4 ^b		16.1 ^b
Tygra	24.8		90.7 ^{ab}		396.5			
USO 31	21.0	69.6 ^{bc}	87.1 ^{bc}	86.8 ^{bc}	301.9	319.3 ^c		13.5 ^d
Average	22.1	75.6	88.5	86.9	423.4	492.7		14.4

Values within a column with the same letter are not significantly different at $p \leq 0.05$.

In 2017 and 2019, plant density was significantly affected ($p \leq 0.05$) by planting date (Table 4). In 2017, April 14 planting resulted in the lowest (8.9) and June 1 the greatest (27.7) plants m^{-2} . The other two planting dates had comparable densities averaged at 18 plants m^{-2} .

Table 4. Comparison of selected characteristics of grain hemp cultivars as affected by planting date. Values are calculated means of different cultivars.

Planting Year	2017				2019		
Planting Date	April 14	May 3	May 17	June 1	April 28	May 9	May 28
Planting Date Ave Temp ($^{\circ}C$)	13	15	23	21	20	24	28
GDD in first 10 days *	167	126	195	185	204	192	230
Rainfall in first 10 days (mm)	19	28	66	6	0	0	77
Plant Density (Plants m^{-2})	8.9 c	20.8 b	16.0 b	27.7 a	69.2 b	86.9 a	71.2 b
Height (cm)	93.0 b	101.1 a	101.1 a	85.7 b	78.3 b	92.0 a	91.7 a
Grain yield (kg ha^{-1})	150.0 c	671.1 a	535.2 a	337.4 b	563.7 a	423.1 b	486.9 b
Thousands seed weight (g)					15.05 a	14.39 b	13.41 c
Crude Protein (g kg^{-1})	233.3 a	234.5 a	238.0 a	219.1 b	256.3 a	244.9 b	252.4 ab
Crude Fat (g kg^{-1})	224.7 ab	238.4 a	237.6 a	200.5 b			
Calcium (%)	0.18 bc	0.16 c	0.18 b	0.22 a	0.17 b	0.18 b	0.21 a
Phosphorous (%)	0.91 a	0.77 b	0.82 b	0.77 b	0.75 a	0.70 b	0.76 a
Potassium (%)	0.87 ab	0.88 a	0.81 b	0.64 c	0.70 a	0.70 a	0.73 a
Magnesium (%)	0.42 a	0.35 c	0.39 b	0.45 a	0.36 b	0.35 b	0.38 a
Sulfur (%)	0.23 b	0.25 a	0.26 a	0.22 b	0.21 b	0.21 b	0.26 a
Iron (mg kg^{-1})	149.8 ab	120.3 c	137.7 b	156.9 a	127.6 c	151.3 b	180.3 a
Copper (mg kg^{-1})	18.6 a	17.8 ab	16.9 b	14.8 c	18.2 a	16.5 b	15.7 b
Zinc (mg kg^{-1})	84.1 a	77.7 b	80.6 ab	84.7 a	70.7 b	70.2 b	83.2 a
Manganese (mg kg^{-1})	109.7 b	137.8 a	137.1 a	139.3 a	109.2 a	97.1 b	106.9 a
Acid Detergent Fiber (g kg^{-1})	466.7 a	435.4 b	458.0 ab	448.0 ab	408.8 a	376.8 b	350.8 c
Total Digestible Nutrient (g kg^{-1})	538.1 b	552.4 a	542.5 ab	544.4 ab	568.7 b	582.3 a	593.3 a

Within a production year, values within a row with the same letter are not significantly different at $p \leq 0.05$. * Growing Degree Days (Base Temp $1^{\circ}C$ —[14]).

Like in 2017, plant densities in 2019 were not affected by cultivar $\times$ planting date interactions. ‘Bialobrzieskie’ had the greatest plant density (93.7 plants m^{-2}) and ‘Joey’ had the lowest. In 2019, the plant densities range from a low of 59 plants m^{-2} in ‘Joey’ to a high of 93.7 plants m^{-2} in ‘Bialobrzieskie’ (Table 3). The second date planting in 2019 gave the greatest plant density at 86.9, while the other two were similar and averaged 70.2 plants m^{-2} . At grain harvest, cultivars differed in height in both 2017 and 2019. For cultivars planted during both production years, ‘Felina 32’ was the tallest and ‘USO 31’ and ‘Canda’ were the shortest in both years (Table 3).

3.4. Grain Yield and Seed Weight

Planting date and cultivar interaction were not significant during both production years. Planting date had a significant ($p \leq 0.05$) effect on grain yield during both years, but the cultivar effect was only significant in 2019. In 2017, all cultivars produced statistically ($p \leq 0.05$) similar yield averaged at 423.4 kg ha^{-1} (Table 3). However, ‘Felina 32’ and ‘USO 31’ produced numerically greater and lower grain yields, respectively. In 2019, ‘Fedora 17’ produced the greatest quantity of the grain (770.9 kg ha^{-1}), while ‘USO 31’ produced the lowest at 319 kg ha^{-1} (Table 3). In 2017, the lowest grain yield was obtained in an April planting followed by planting in June. The two planting dates in May produced the greatest grain yield averaged at 603.1 kg ha^{-1} (Table 4). In 2019, the first planting in April produced the greatest amount of grain (563.7 kg ha^{-1}) compared to the two plantings in May, whose yield was averaged at 455 kg ha^{-1} (Table 4).

3.5. Grain Nutrient Element Composition

3.5.1. Macronutrient Content

In 2017, seeds of the three cultivars had comparable P content that ranged from a low of 0.77% for ‘Tygra’ to a high of 0.84% for ‘USO 31’ (Table 5). ‘USO 31’ and ‘Canda’ had comparable contents of K averaged at 0.85% that was greater ($p \leq 0.05$) than that of ‘Tyra’ and ‘Felina 32’. Like for P, ‘USO 31’ had greater content of Ca (0.21%) and Mg (0.40%) compared to ‘Tygra’ with 0.17% Ca and 0.38% Mg. All cultivars had comparable amounts of S (0.24%). In 2019, ‘Joey’ had the greatest content of P (0.76%), and ‘Canda’ and ‘Fedora 17’ had the lowest Ca content, averaged at 0.17%. ‘Canda’ also had the lowest S content of 0.19%; all others averaged 0.23%. Potassium and Mg content were comparable among all cultivars and averaged 0.72% and 0.36%, respectively. During both years, planting dates significantly ($p \leq 0.05$) affected the seed macronutrient contents. Seed Ca, Mg, and S contents were, in general, greater for a later compared to an earlier planting date (Table 4). However, K and P tended to be higher in early planting or did not change significantly from one planting date to the next.

Table 5. Comparison of macronutrient element contents of hemp grain. Values are calculated means of different planting dates.

Cultivars	Calcium		Phosphorous		Potassium		Magnesium		Sulfur	
	2017	2019	2017	2019	2017	2019	2017	2019	2017	2019
	%									
Bialobrzekie		0.19 ^{ab}		0.73 ^{ab}		0.72		0.36		0.23 ^a
Canda	0.18 ^b	0.16 ^b	0.83 ^a	0.75 ^{ab}	0.84 ^a	0.70	0.38 ^{bc}	0.35	0.24	0.19 ^b
Fedora 17		0.17 ^b		0.74 ^{ab}		0.72		0.36		0.23 ^a
Felina 32	0.19 ^{ab}	0.19 ^{ab}	0.82 ^{ab}	0.71 ^b	0.72 ^b	0.69	0.41 ^a	0.37	0.24	0.23 ^a
Joey		0.17 ^b		0.76 ^a		0.71		0.36		0.23 ^a
Tygra	0.17 ^b		0.77 ^b		0.77 ^b		0.38 ^c		0.24	
USO 31	0.21 ^a	0.21 ^a	0.84 ^a	0.70 ^b	0.86 ^a	0.75	0.40 ^{ab}	0.36	0.24	0.23 ^a
Average	0.19	0.18	0.82	0.73	0.80	0.72	0.39	0.36	0.24	0.22

Values within a column with the same letter are not significantly different at $p \leq 0.05$.

3.5.2. Micronutrient Content

In 2017, seeds of the four cultivars had similar ($p \leq 0.05$) contents of Fe and Mn averaged at 141 and 131 mg kg^{−1}, respectively (Table 6). However, for Zn and Cu, significant cultivar differences ($p \leq 0.05$) were observed. ‘Canda’ and ‘USO 31’ had similar Zn contents averaged at 85.5 mg kg^{−1}, which was greater than that of ‘Felina 32’ and ‘Tygra’, averaged at 78.0 mg kg^{−1} (Table 6). In 2019, Fe and Zn contents were not significantly different ($p \leq 0.05$) and across all seven cultivars averaged 152 and 82 mg kg^{−1}, respectively. ‘Fedora 17’ had more Mn (113.2 mg kg^{−1}) than all cultivars except ‘Felina 32’ (Table 6).

Table 6. Comparison of micronutrient element contents of hemp grain. Values are calculated means of different planting dates.

Cultivars	Iron		Zinc		Manganese		Copper	
	2017	2019	2017	2019	2017	2019	2017	2019
	mg kg ^{−1}							
Bialobrzekie		156.4		73.3		101.4 ^b		16.4 ^b
Canda	141.9	145.3	85.9 ^a	73.0	131.3	104.3 ^b	17.9 ^a	18.4 ^a
Fedora 17		147.9		72.8		113.2 ^a		16.5 ^b
Felina 32	146.2	149.9	79.6 ^b	69.3	136.5	106.1 ^{ab}	16.1 ^b	17.4 ^{ab}
Joey		158.4		78.7		99.5 ^b		16.4 ^b
Tygra	139.9		76.3 ^b		127.3		17.3 ^a	
USO 31	136.8	152.7	85.4 ^a	78.9	128.9	101.3 ^b	16.9 ^{ab}	16.4 ^b
Average	141.2	151.8	81.8	74.3	130.9	104.3	17.0	16.9

Values within a column with the same letter are not significantly different at $p \leq 0.05$.

However, ‘Canda’ Cu content of 18.4 mg kg⁻¹ was greater than that of all other cultivars except ‘Felina 32’. During both production years, seed micronutrient contents were significantly ($p \leq 0.05$) affected by planting dates (Table 7). Seed Fe and Zn contents were generally greater for later compared to earlier plantings, while Mn and Cu contents were lower for later compared to earlier planting dates.

Table 7. Comparison of nutrition quality characteristics (Crude Protein (CP); Crude Fat (Cfat); Acid Detergent Fiber (ADF); and Total Digestible Nutrient (TDN)) of hemp grain. Values are calculated means of different planting dates.

Cultivars	CP		Cfat		ADF		TDN	
	2017	2019	2017	2019	2017	2019	2017	2019
	g kg ⁻¹							
Bialobrzeskie		258.2 ^a				355.3 ^c		593.9 ^a
Canda	236.3	243.1 ^c	219.6 ^{bc}		442.5	416.1 ^a	547.7	564.1 ^c
Fedora 17		257.3 ^{ab}				376.4 ^{bc}		582.9 ^{ab}
Felina 32	223.4	246.4 ^{abc}	238.0 ^{ab}		449.8	376.3 ^{bc}	545.0	583.0 ^{ab}
Joey		246.0 ^{bc}				397.8 ^{ab}		571.2 ^{bc}
Tygra	231.5		248.6 ^a		462.6		541.6	
USO 31	233.6 ^a	254.0 ^{abc}	195.0 ^c		450.0	365.4 ^{bc}	543.2	587.0 ^{ab}
Average	231.2	250.8	225.3		451.2	381.2	544.4	580.4

Values within a column with the same letter are not significantly different at $p \leq 0.05$.

3.6. Grain Nutritional Composition

In 2017, no differences were observed in grain crude protein (CP) content between cultivars (Table 7). Across cultivars, CP content averaged 231.2 g kg⁻¹. However, grain crude fat was significantly greater in ‘Tygra’ (248.6 g kg⁻¹) compared to ‘USO 31’ (195.0 g kg⁻¹). Grain ADF and TDN were not significantly different ($p \leq 0.05$) between hemp cultivars and averaged 451.2 and 544.4 g kg⁻¹, respectively. Planting date affected both CP and Crude fat, with grain from the last planting in June had the lowest amounts compared to that of grain from crops planted earlier. In 2019, ‘Bialobrzeskie’ grains had the greatest CP (258.2 g kg⁻¹) and ‘Canda’ the least (243.1 g kg⁻¹). In contrast, ‘Bialobrzeskie’ had the least ADF and greatest TDN compared to ‘Canda’ (Table 4). In 2019, there was no specific pattern for CP and planting date with an early planted crop-producing grain of greater CP content (256.3 g kg⁻¹) than the second (244.9 g kg⁻¹) and both were similar to the CP content of grain from the third planting (252.4 g kg⁻¹). In 2019, ADF was greatest and lowest in grain from first and third planting, respectively. Conversely, TDN was lowest (568.7 g kg⁻¹) in grain of a crop planted early compared to that planted late (593.3 g kg⁻¹) (Table 4).

3.7. Fiber Hemp Cultivars

In 2017, ‘Carmagnola’ and ‘Wojko’ had similar plant densities that averaged 67.1 plants m⁻², a density significantly ($p \leq 0.05$) lower than that of the other three cultivars whose densities were comparable and averaged 176 plants m² (Table 8). All three cultivars grown in 2019 had comparable plant density averaged at 135 plants m². In 2017, ‘Carmagnola’ had the greatest height at harvest (158.20 cm), while ‘Futura 75’ and ‘Wojko’ were the shortest and averaged 107 cm (Table 8). Similarly, in 2019, ‘Carmagnola’ was significantly taller than ‘Fedora 17’ and ‘Futura 75’. In 2017, ‘Carmagnola’ had the greatest biomass yield (3.31 t ha⁻¹), and ‘Bialobrzeskie’ and ‘Fedora 17’ had the lowest biomass at 1.36 and 1.60 t ha⁻¹, respectively. In 2019, the grown cultivars produced numerically greater biomass than in 2017. During this production year, ‘Carmagnola’ gave significantly greater biomass (8.62 t ha⁻¹), and ‘Fedora 17’ and ‘Futura 75’ produced similar and lower biomass averaged at 4.35 t ha⁻¹ (Table 8).

Table 8. Comparison of different character traits of fiber hemp as affected by cultivar. Values are calculated means of different planting dates.

Cultivars	Plant Density (pop m ⁻²)		Height (cm)		Biomass Yield (t ha ⁻¹)	
	2017	2019	2017	2019	2017	2019
Bialobrzekie	171.9 ^a		76.1 ^c		1.36 ^c	
Carmagnola	78.5 ^b	120.0	158.2 ^a	166.4 ^a	3.31 ^a	8.62 ^a
Fedora 17	195.7 ^a	148.9	79.8 ^c	90.3 ^b	1.60 ^c	4.04 ^b
Futura 75	160.6 ^a	137.3	106.5 ^b	108.3 ^b	2.56 ^b	4.63 ^b
Wojko	55.7 ^b		107.5 ^b		1.94 ^{bc}	
Average	132.5	135.4	105.6	121.7	2.15	5.76

Values within a column with the same letter are not significantly different at $p \leq 0.05$.

The planting date significantly affected the height of the plant at harvest for the 2017 production year. The first two plantings had the tallest plants averaged at 134.5 cm (Table 9), while plants established June 1 had the shortest plants (89.2 cm). Biomass was similar across planting dates for both years, though early planting tends to give numerically greater values and especially in 2019. Late planting gave greater values for plant density during both years.

Table 9. Comparison of different character traits of fiber hemp based on their planting date.

Planting Year	2017				2019		
	April 14	May 3	May 17	June 1	April 28	May 9	May 28
Planting Date	April 14	May 3	May 17	June 1	April 28	May 9	May 28
Planting Date Ave Temp (°C)	13	15	23	21	20	24	28
GDD in first 10 days [†]	167	126	195	185	204	192	230
Rainfall in first 10 days (mm)	19	28	66	6	0	0	77
Biomass yield (t ha ⁻¹)	2.36 ^a	2.28 ^a	2.48 ^a	2.31 ^a	6.00 ^a	6.27 ^a	5.02 ^a
Height (cm)	129.7 ^a	139.3 ^a	110.5 ^b	89.2 ^c	123.9 ^a	127.0 ^a	114.2 ^a
Plant Density (Plants m ⁻²)	75.5 ^b	53.0 ^b	85.0 ^b	171.0 ^a	105.1 ^b	147.9 ^a	153.2 ^a

[†] Growing Degree Day with base temperature 1 °C [14]. Values are calculated means of different cultivars. Values within a column with the same letter are not significantly different at $p \leq 0.05$.

4. Discussion

The relationship between growth stages and GDD is useful for the timing of planting and management practices (fertilizing, pest, disease and weed control, pollination) and assessing cultivar performance under different climates [8].

In this study all hemp cultivars showed the same GDD requirements from planting to appearance of the first pair of leaves, but there were some differences in CGDD effect on later phenological and morphological growth phases. A similar finding was obtained in a study conducted on 14 cultivars in Latvia, the Czech Republic, France, and Italy [48]. In the study, a variation in stem and seed yield among genotypes was mainly determined by the difference in flowering time, a growth phase under the control of temperature and photoperiod. Amaducci et al. [49] also reported that the flowering time in hemp could vary greatly with the latitude of production site.

Cultivars that need more GDD to complete every growth stage of its life cycle may be successfully produced in areas with the longer growing season. In our study, while grain-type cultivar like ‘USO 31’ shows an early transition to the reproductive phase (flower primordia formation at stage 51 BBCH), fiber-type cultivar ‘Carmagnola’ transitioned later. Similar results were reported for ‘USO 31’ in Italy where among eight cultivars, it flowered earlier [50]. The early flowering in ‘USO 31’ was reportedly due to requirement of short GDD for both pre- and post-flowering periods [51]. A late flowering cultivar results in lower grain yield while stem biomass at flowering was highest for late flowering cultivar and when planted early [48]. A late monoecious cultivar, which, if sown early enough, could provide appreciable biomass and seed yield may be a good dual crop [52].

In our study, among grain hemp cultivars, ‘Bialobrzeskie’ showed the highest plant density while ‘Tygra’ had the worst, and in general, plant survival in 2017 was lower than in 2019. High rainfall in May of 2017 could have increased fungal infections and death of germinated seeds and young seedlings and may have contributed to reduced plant density compared to 2019. In addition, the initial poor germination potential of some cultivars may have affected density because some cultivars had no germination percent information, and no germination test was carried out prior to planting the seeds. Similarly, soil conditions at planting may have affected seed germination and emergence and therefore subsequent plant population. Excessive soil moisture results in poor aeration and increased potential soil-borne fungal infestation, while dry condition leads to poor germination and poor seedling emergence through the soil crushed.

Low plant density may have contributed to the observed reduction in grain yield and biomass yield in some cultivars in 2017. Differences in 1000 seed weight among cultivars, which ranges from 17.50 g (‘Canda’) to 12.10 g (‘Bialobrzeskie’), can be attributed to plant genetics. However, low seed weight for late-planted crops may be a result of accelerated seed maturity and poor seed-fill that occurred during the hot summer. The seed weight for crops planted early was comparable to that found for the same cultivars in New York [53].

‘Fedora 17’ grain yield of 770.9 kg ha⁻¹ in 2019 was slightly lower, and ‘USO 31’ was far lower than those reported in France [54]; this indicates that potential exists for improving yield at this location. ‘Felina 32’ gave a relatively good yield during both production years, a trend previously reported in New York when compared to 13 other cultivars [55]. Baldini et al. [50] reported ‘Fedora 17’ to produce greater seed yield than eight other cultivars across multiple years. In our study, a lot of seeds were lost in shattering and to feeding birds; this could contribute to the observed low yields. Cultivar ‘USO 31’ is known as a very early variety and its growing season (from sowing date till the first matured seed) was 18–20 weeks while for the other eight hemp cultivars was 20–22 weeks in Lithuania [56]. ‘USO 31’ showed a short growth period to seed maturity in Virginia (Figure 2), and this may have increased its potential for early bird infestation, resulting in comparatively greater seed loss and the lower seed yield compared to other cultivars. The seed protein and oil contents, the nutritional components of hemp seeds, and the fatty acid composition are mainly affected by genetic factors [57]. In our study, seed protein, oil, and mineral elements iron, manganese, and zinc contents were comparable to those reported in other studies [27].

Differences in heights at harvest may be due to differences in genetic background. However, cultivars were generally shorter than those reported in other studies [58]. This may be an indication that conditions at this location may be suboptimal for these cultivars’ performance and that there exists room for improved performance through better management. Planting early allowed for a longer vegetative growth prior to switching to the reproductive phase, and a crop grown in April to mid-May was taller than those grown in June. Ferfua et al. [52] have reported that delayed sowing contributes to reduced plant height in Italy. Mid-late and late flowering varieties such as Bialobrzeskie and Futura 75 scored intermediate for fiber yield [59]. In our study for the fiber-type cultivars like ‘Carmagnola’ and ‘Futura 75’, yield was less than 50% of that reported by others [60,61]. While these previous studies occurred in Europe, a continent with a long history of industrial hemp production, it is an indication that there exists a huge potential for greater yield here at Virginia. The low biomass observed with greater plant density in this study supports previous findings [60] on the relationship between plant density and biomass. Reduced biomass at high plant populations has been reported [62] and dense plants had a tendency to flower short and had smaller diameter, factors that will result in a reduction in biomass yield [63].

5. Conclusions

Upon completion of various evaluations, ‘Fedora 17’ grain yield and quality was good under Virginia conditions and would preferably be considered for producing grain.

Similarly, among the fiber cultivars, ‘Carmagnola’ produced appreciable dry biomass and would be a good candidate for production as a fiber cultivar under Virginia’s condition. While most of the cultivars in this study were evaluated for only a single use, it would be good to test them for alternative uses. For example, while ‘Futura 75’ and ‘Carmagnola’ also have potential to be used for grain, and CBD, both were tested only for biomass. Because transition to flowering hinders vegetative growth, and redirect resources to reproductive growth, cultivars that show early flowering are better suited for grain, but late-flowering cultivars that allow for extended vegetative growth are good for fiber production. For both grain and fiber type cultivars, planting early will result in a long vegetative growth phase, robust plant growth, and may result in better yields.

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