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Multi-Year Insights into Industrial Hemp Growth in a Mediterranean Climate

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Abstract: Hemp (*Cannabis sativa* L.) is a rapidly growing plant with multipurpose uses, and the optimal combination of yield and quality of hemp products (fibers, inflorescences, or seeds) may provide economic opportunities to uncover the full spectrum of its capabilities. The presented experimentation took place over seven years (2017–2023) in Greek climatic conditions for fourteen (14) registered monoecious and dioecious varieties. It can be concluded that the production of biomass, fiber, and seed weight were different not only between varieties but also from year to year. Despite significant variation between harvest years in biomass yield, the extracted fiber was relatively constant. Moreover, not only the dioecious varieties but also the monecious varieties could be effectively grown for biomass production in Greece. Regarding fiber production, monoecious varieties had the highest yields, apart from the dioecious Kompolti variety, which was the most fiber-productive. Under the experimentation conditions, early flowering varieties were most suited for seed production, and the KC Dora variety produced the heavier seeds. Generally, the Futura 75 variety was one of the most productive varieties for biomass and seed weight, while the Bialobrzeskie variety produced the greatest amounts of fiber.

Keywords: industrial hemp; biomass; fiber content; weight of 1000 seeds

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1. Introduction

Hemp belongs to the family Cannabaceae and is classified under the Cannabis genus as one species, *Cannabis sativa* L., with many varieties [1]. It is one of the world's most recognizable plants, which was rediscovered as a sustainable and high-yielding crop. Historically valued for its bast fibers, used in cordage and textiles, as well as its seeds, which have been utilized for food and seed oil, hemp has gained further attention for its inflorescences, which contain compounds used in medicinal and psychoactive drugs [2]. The global hemp market is diverse, comprising millions of products, with new applications continually emerging. This growing market reflects the versatility and potential of hemp across various industries, including textiles, food and nutrition, pharmaceuticals, and more [3].

Hemp is characterized, as an annual, wind-pollinated crop, with both dioecious and monoecious varieties [4]. Genotype, environment, and crop management are the primary elements that influence hemp's yield and performance in the field; more specifically, plant density, nutrition, and irrigation level are crucial for plant growth, development, and the synthesis of key cannabinoids compounds [5,6]. Crop cultivation takes place in well-drained and medium–heavy soils, and cannabis plants require moderate fertilization. Sowing mainly takes place from March to May in the Northern Hemisphere and the time required from sowing to harvesting the plant is 3–4 months [7].

However, hemp farmers face several challenges that require scientific and technical solutions in order to optimize production. These challenges include choosing the most appropriate variety according to the end use, using the most efficient production techniques, and having access to appropriate harvesting equipment and procedures [8]. The primary objective of this study is to evaluate various hemp varieties within the specific environmental conditions in Greece. By conducting field experiments, the study aims to provide Greek farmers with valuable insights to facilitate decisions regarding the selection of hemp varieties best suited to their specific production goals and end products. As research and development on hemp continue to uncover the full spectrum of hemp's capabilities, its role as a valuable and multifaceted crop is poised to expand further, driving innovation and economic opportunities not only in Greece but worldwide.

2. Materials and Methods

During the years 2017–2023, a total of 14 hemp varieties of diverse European origin were cultivated at the campus of the Institute of Plant Breeding and Genetic Resources (IPBGR) in Thessaloniki, Greece. The studied varieties were both monoecious (10 varieties with both female and male flowers on the same inflorescence) and dioecious (4 varieties with different male and female plants). The origin of the tested varieties is presented in Table 1, along with the abbreviated names used in this paper. The seed-oriented variety Finola (FIN) was cultivated for seed production only in the year 2017. All the varieties were registered to the European Catalogue with Δ9 tetrahydrocannabinol (THC) content < 0.3%.

Table 1. Tested varieties during the cultivation years 2017–2023.

				Year of Cultivation						
Registered Variety	**Brief Name**	**Origin**	**Sexual Type**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
BIALOBRZESKIE	BLB	Poland	monoecious	X [1]	X	X	X	X	X	
CARMAGNOLA	CRM	Italy	dioecious			X	X	X		
CARMAGNOLA SELEZIONATE	CS	Italy	dioecious			X	X	X	X	X
FEDORA 17	F17	France	monoecious	X	X	X	X	X	X	X
FELINA 32	F32	France	monoecious	X	X	X	X	X	X	X
FERIMON	FRM	France	monoecious		X	X	X	X	X	X
FUTURA 75	F75	France	monoecious	X	X	X	X	X	X	X
KC DORA	KCD	Hungary	monoecious			X	X	X	X	X
KOMPOLTI	KMP	Hungary	dioecious						X	X
SANTHICA 27	S27	France	monoecious	X	X	X	X	X	X	
SANTHICA 70	S70	France	monoecious			X	X	X		X
TIBORZALLASI	TBR	Hungary	dioecious						X	X
TYGRA	TGR	Poland	monoecious	X	X	X	X	X	X	X
USO 31	U31	Ukraine	monoecious		X	X	X	X	X	X

[1] 'X' indicates that the corresponding variety was tested in the specified year.

The experimental fields were established at the campus of IPBGR. In particular, the years 2017, 2019, 2021, and 2023 were recorded at the field (A = 40.536416 N, 23.001569 E), while the years 2018, 2020, and 2022 were recorded at a nearby field (B = 40.536440 N, 23.006912 E), due to crop rotation issues. The soil type of each field is presented in Table 2.

Table 2. Soil characteristics of the experimental fields in the cultivation years 2017–2023.

Year	Sand (%)	Silt (%)	Clay (%)	pH	Organic Matter (%)	EC (mS/cm)	NO_3-N (mg/kg)	P (mg/kg)	K (mg/kg)
Field A									
2017	38	40	22	7.9	1.4	0.491	7.0	9.0	471
2019	48	36	16	7.8	1.6	0.555	13.5	13.43	607
2021	40	38	22	7.7	1.3	0.443	3.6	10.7	320
2023	42	36	22	7.7	2.2	0.472	7.8	9.1	337
Field B									
2018	50	36	14	7.6	1.1	0.74	10.5	4.1	115
2020	42	42	16	7.8	1.4	1.183	18.3	7.6	169
2022	52	34	14	7.9	1.2	0.451	7.1	3.6	138

Hemp was hand-seeded at seed rate of 30 kg ha^{-1}, as proposed by [9] as optimal for biomass production, in plots of 10 m length with 80 cm distances between rows. Each plot consisted of 4 rows of hemp, and plots were arranged in a randomized complete block design, with at least 3 replications for each variety.

In all experimental fields, the seedbed was prepared with a moldboard followed by disc-harrowing. One day before sowing, basic fertilization was applied in all experiments (Table 3), which included nitrogen in the form of ammonium sulfate ($(NH_4)_2SO_4$), phosphorus as triple superphosphate ($Ca(H_2PO_4)_2$), and potassium as potassium sulfate (K_2SO_4), in 20.5-0-0, 0-46-0 and 0-0-50 fertilizers, respectively. Topdressing nitrogen as ammonium nitrate (NH_4NO_3) in a 33.5-0-0 fertilizer was applied at the beginning of blossoming each year.

Table 3. Fertilization rate and quantity and harvesting days after sowing (DAS) for biomass and seeds yield, in the cultivation years 2017–2023.

		Fertilization Rate kg ha^{-1}				Harvesting	
		Basic			N-Topdressing	DAS	
Year	**Sowing Date**	**20.5-0-0**	**0-46-0**	**0-0-50**	**33.5-0-0**	**Biomass**	**Seeds**
2017	3 April	350	330	0	200	99	130
2018	12 April	350	300	150	150	95	110
2019	3 April	250	300	0	150	97	110
2020	14 April	200	300	100	200	105	125
2021	6 April	450	330	50	300	95	110
2022	12 April	350	300	100	300	95	120
2023	25 April	400	330	50	200	110	130

The experimental area was sprinkled and irrigated until crop emergence; thereafter, drip irrigation was applied whenever needed. No pesticides were applied during cultivation periods, and the weeds were hand-hoed, as needed.

The climate at the experimental area is characterized as a typical Mediterranean climate, with a warm dry summer and a cool humid winter. The mean monthly temperatures are presented in Table 4 and the total monthly and yearly rainfall data, which were recorded near the experimental area (over a distance of approximately 1000 m), are shown in Figure 1.

Table 4. Average temperature (°C) during hemp-growing season in the cultivation years 2017–2023.

	Average Temperature (°C)				
	April	**May**	**June**	**July**	**August**
2017	14.4	19.7	25.1	26.6	27.1
2018	16.8	21.0	23.7	26.4	26.2
2019	14.5	19.6	25.9	27.1	28.2
2020	13.4	19.6	24.0	27.1	26.7
2021	13.3	20.6	24.4	28.6	28.6
2022	14.7	20.7	25.6	27.5	27.1
2023	14.0	18.0	23.3	28.8	27.8

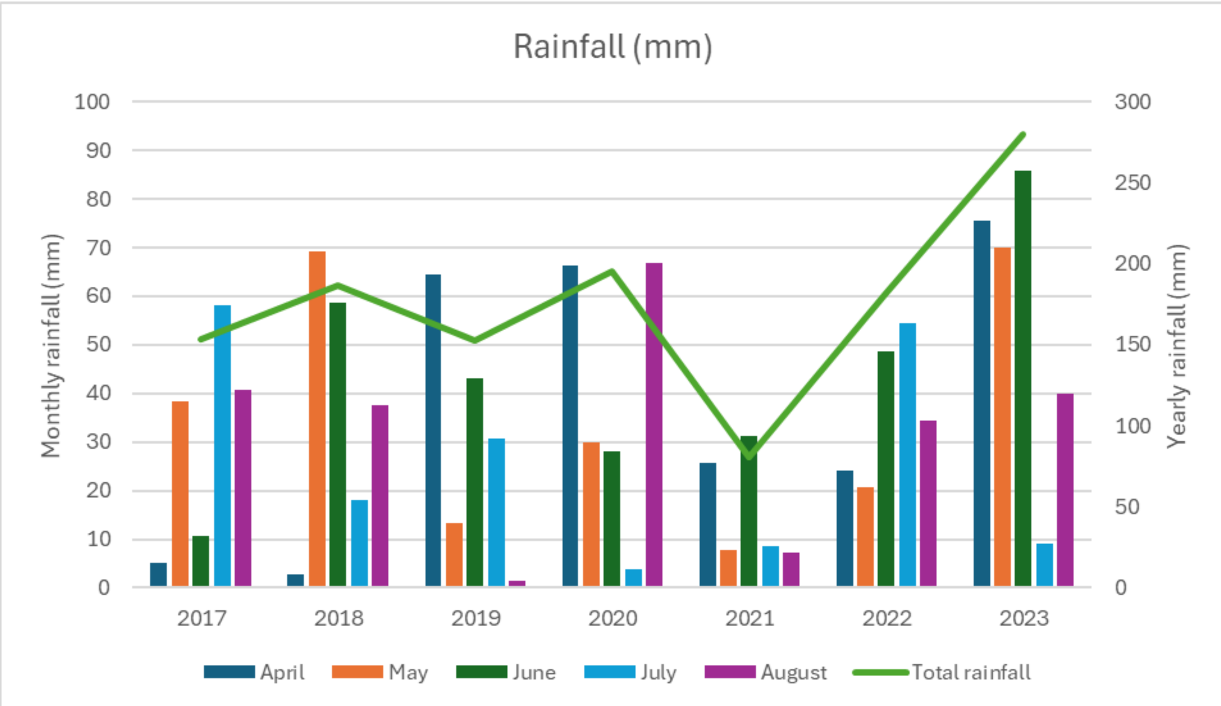

Figure 1. Monthly and yearly rainfall (mm) in the cultivation years 2017–2023.

Each year of the experimentation, the hemp plants that grew in one of the central rows of each plot were hand-harvested, at the growing stage code 2305 (beginning of seed maturity), and the total fresh biomass was determined using a digital scale (DELMAC Instruments, EU). The stems were separated from the inflorescences and, after wet retting, the % of fibers were estimated, as described previously by Tsaliki et al. [6]. At seed harvest (growing stage code 2307—end of seed maturity) [10], the hemp plants growing in the other central row of each plot were also cut and air-dried. After drying, the seeds were separated from the leaves and stems using shivers and an aspirator (model Selecta Zig Zag, PETKUS Selecta, Hem, The Netherlands). The 1000-seed weight was evaluated with the laboratory counter (MEZOS spot s.r.o., Hradec Králové, Czech Republic) three times per sample. The exact days after sowing (DAS) that harvesting took place in the experimentation years are presented in Table 3.

The statistical analysis included standard descriptive statistics for the quantitative variables (medians, means, and bar charts) and hypothesis testing to evaluate the differences among the varieties considered. For the latter, the non-parametric Kruskal–Wallis test was employed to assess the overall differences in fresh biomass, fibers, and seed weight among the varieties considered, separately for each year. In the case the overall difference was statistically significant ($p < 0.05$), a post hoc analysis was performed in order to further assess the pairwise differences among the varieties. The p-values that were computed within the post hoc analysis were adjusted to take into account multiple comparisons, using the false discovery rate (FDR) approach. For analysis and visualization purposes, the "ggstatsplot" R package was employed [11]. The level of statistical significance was set to 0.05, while pairwise differences with an adjusted p-value between 0.05 and 0.10 were considered to be marginally significant. The analysis was performed using R version 4.3.3.

3. Results

3.1. Fresh Biomass Production (t ha^{-1})

The assessment of median fresh biomass yield values across different hemp varieties over the cultivation years indicated significant differences among the varieties (Figure 2). In 2017, yields ranged from 15.0 t ha^{-1} for the F17 variety to 21.56 t ha^{-1} for F75, with no statistically significant differences overall among the varieties (p = 0.78). The subsequent years revealed notable fluctuations in fresh biomass production. In 2018, yields ranged from 27.5 t ha^{-1} for BLB to 46.25 t ha^{-1} for F75 (overall p = 0.07). Following this, in 2019, the CS variety exhibited the highest productivity at 38.12 t ha^{-1}, while F17 displayed the least efficiency with 15.62 t ha^{-1} (overall p = 0.06). The years 2020 and 2021 showcased S70 as the most efficient variety, yielding 42.81 t ha^{-1} and 55.0 t ha^{-1}, respectively. Conversely, U31 yielded the lowest biomass in 2020 at 15.0 t ha^{-1}, while F17 recorded the lowest yield in 2021 at 12.5 t ha^{-1}. In 2020, the p-value of 0.003 showed that there were overall statistically significant differences among the twelve tested varieties, while the p-value of 0.07 in 2021 showed that the same varieties were marginally statistically different. In 2022, F17 remained the least efficient, yielding 19.38 t ha^{-1}, while TBR emerged as the most productive at 73.13 t ha^{-1}, with an overall p-value of 0.02. Similarly, TBR continued its dominance in 2023, recording the highest yield of 75.0 t ha^{-1}, whereas F75 exhibited the lowest productivity with 30.0 t ha^{-1} (overall p = 0.03).

The F17 variety consistently demonstrated the lowest productivity in fresh biomass across the years 2017, 2019, 2021, and 2022 among all varieties. Furthermore, in the remaining years, F17 consistently occupied one of the bottom four positions for biomass yield, ranging from 12.5 t ha^{-1} (2021 year) to 36.25 t ha^{-1} (2023). This consistent performance underscores the comparatively lower efficiency of the F17 variety in fresh biomass production when compared to other assessed varieties. The F75 variety demonstrated notable variability in biomass productivity over the years, exhibiting the highest yield of all tested varieties in both 2017 and 2018. However, this efficiency fluctuated across subsequent years, as indicated by its low productivity in 2023 in comparison with the others, when it emerged as the least productive variety. Despite this fluctuation, it is worth mentioning that the overall biomass yield of the F75 variety in 2023 surpassed that of 2017. This supports the fact that, although F75 may not have performed as well as other varieties in 2023, its biomass production remained relatively high, possibly due to genetic characteristics or environmental conditions. In general, the F75 biomass yield ranged from 21.56 t ha^{-1} in both 2017 and 2019 to 52.50 t ha^{-1} in 2022.

In 2020, the post hoc analysis (Supplementary Table S1) showed marginal statistically significant differences (p-value < 0.10) in pairwise comparisons between varieties. In particular, S70, the highest yielded variety, differed from F17, F32, FRM, S27, TGR, and U31, CS differed from F17, F32, FRM, TGR, and U31, F75 differed from F17, F32, FRM, TGR, and U31, and CRM varied only from TGR and U31.

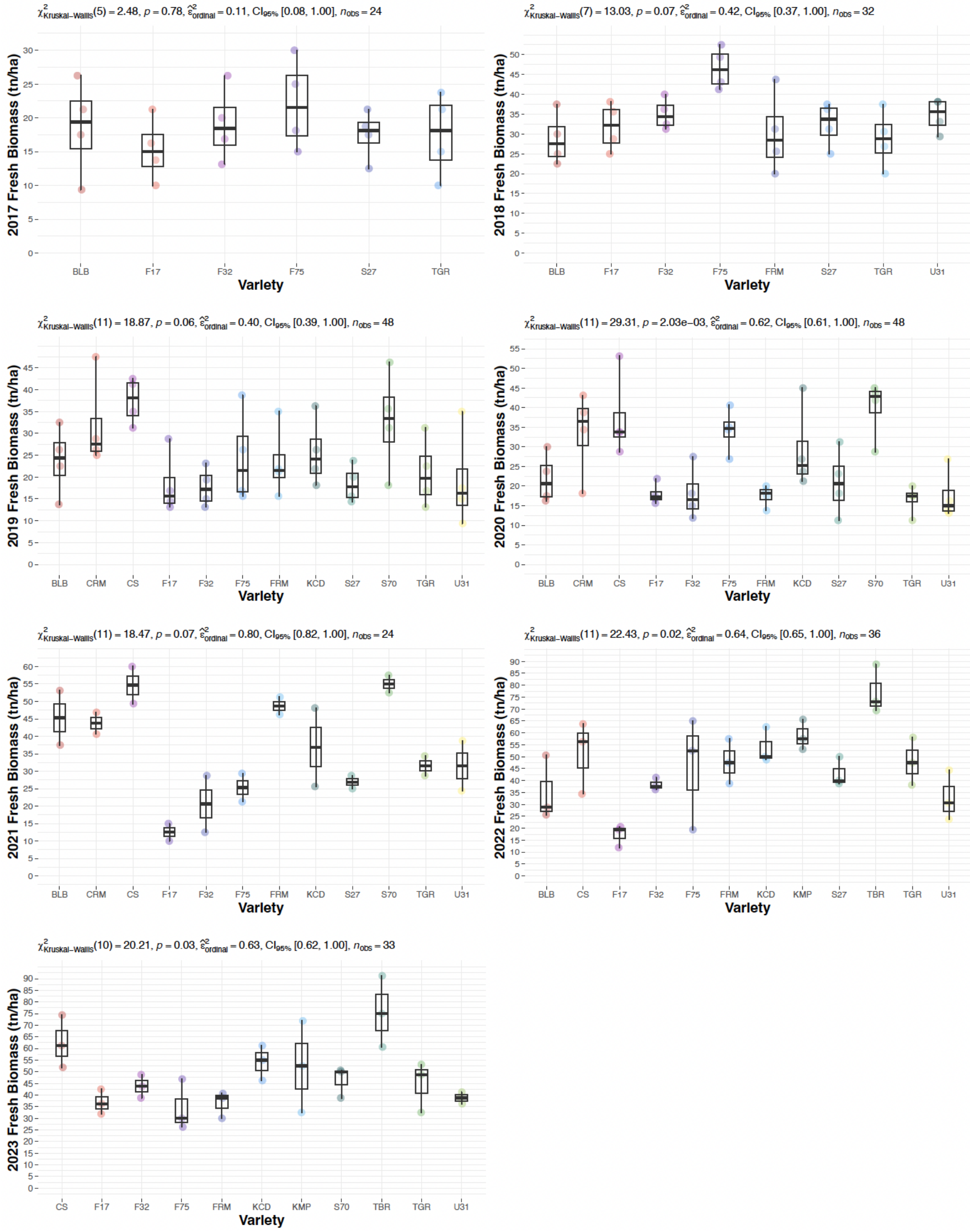

Figure 2. Fresh biomass production (t ha^{-1}) of the tested varieties in 2017–2023. The varieties' names are abbreviated as follows: Bialobrzeskie: BLB; Carmagnola: CRM; Carmagnola Selezionate: CS; Fedora 17: F17; Felina 32: F32; Ferimon: FRM; Futura 75: F75; KC Dora: KCD; Kompolti: KMP; Santhica 27: S27; Santhica 70: S70; Tiborszallasi: TBR; Tygra: TGR; Uso 31: U31.

3.2. Fiber Content (%)

Figure 3 presents the median fiber content (%) values of the tested varieties for the years 2017–2023. The overall comparison of the varieties in each year showed that there were statistically significant differences in all the years between 2017 and 2023 (p-values: 0.04, <0.001, 0.002, <0.001, 0.05, 0.001, and 0.002, respectively). Throughout the seven years of experimentation, the CS variety had the lowest median fiber yield in the years 2020 and 2021, and TBR had the lowest in 2022 and 2023. Among the varieties, KMP was the most fiber-productive in the last two years of experimentation (as it was only tested in these years), followed by FRM with 32.05% in 2018 and BLB with 31.5% in 2020.

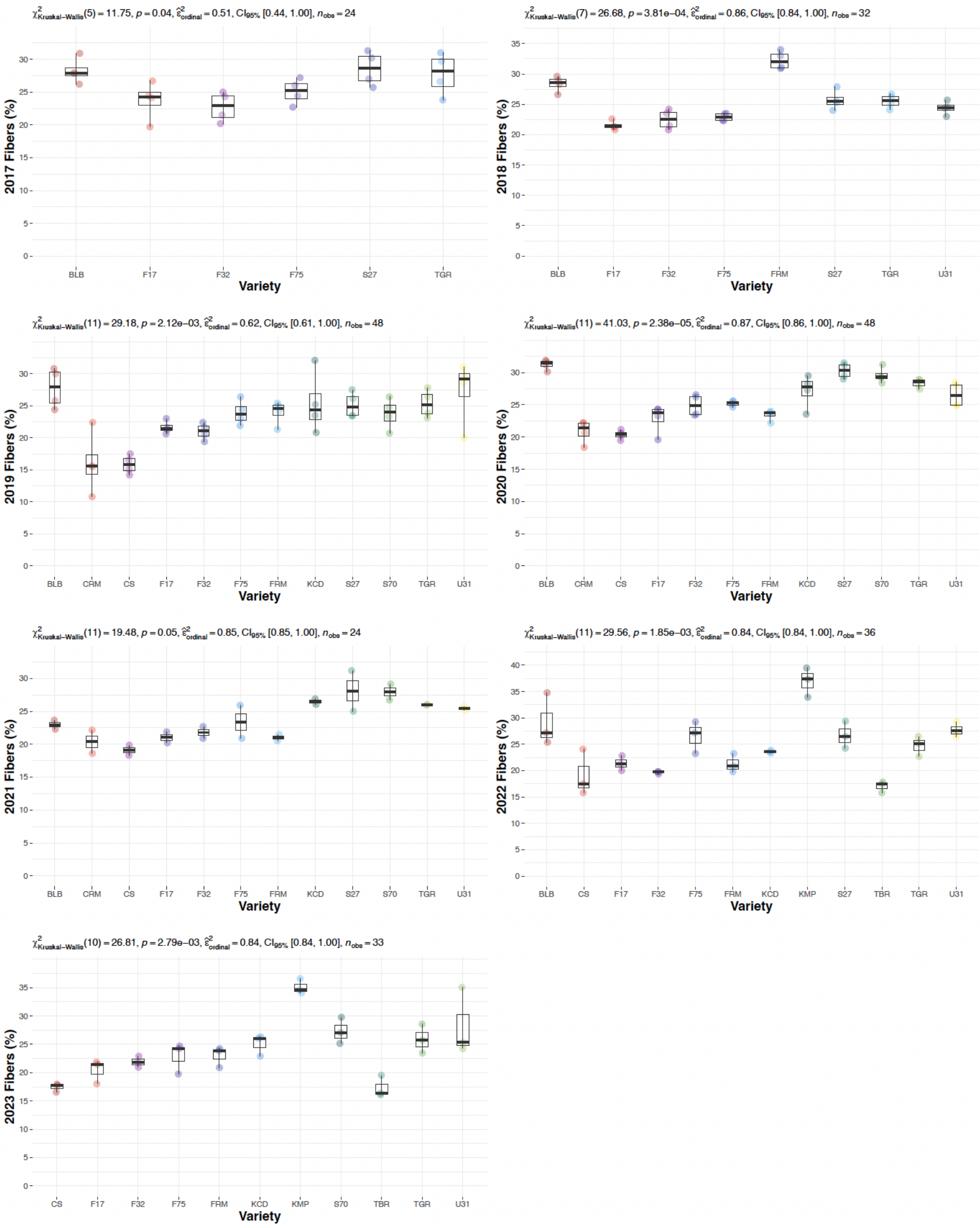

Figure 3. Fiber content (%) of the tested varieties in the 2017–2023 years. The varieties' names are abbreviated as follows: Bialobrzeskie: BLB; Carmagnola: CRM; Carmagnola Selezionate: CS; Fedora 17: F17; Felina 32: F32; Ferimon: FRM; Futura 75: F75; KC Dora: KCD; Kompolti: KMP; Santhica 27: S27; Santhica 70: S70; Tiborszallasi: TBR; Tygra: TGR; Uso 31: U31.

In 2017, the S27 variety had the highest median fiber percentage at 28.6%, while the F32 variety had the lowest at 22.9%. The fiber content of F32 differed marginally but to a statistically significant extent in the post hoc analysis (Supplementary Table S2) not only from S27 but also from BLB. In 2018, the F17 variety exhibited the lowest median fiber yield, at 21.3%, whereas the FRM variety demonstrated the highest median fiber yield, at 32.05%. The fiber content of FRM was statistically significantly different from the F32, F75, and F17 varieties (*p*-values: 0.007, 0.007, and 0.002, respectively) and marginally from

U31 (p = 0.081). Additionally, the BLB variety showed significant differences in fiber yield compared to F17, F32, and F75 (p-values: 0.007, 0.041, and 0.041, respectively), while F17 also differed marginally, but to a statistically significant extent, from the S27 and TGR varieties (both p-values: 0.079). In 2019, the U31 variety had the highest fiber content of 29.2%, which was statistically different from CRM and CS (p-values: 0.053 and 0.035), while the CRM variety had the lowest, at 15.55%. The CS variety also showed statistically significant differences from BLB (p-value 0.028), and marginally from FRM, KCD, S27, and TGR, while the CRM variety differed significantly from BLB (p-value 0.035), and marginally from S27, TGR, and, as mentioned before, U31.

In 2020, among the total of twelve tested varieties, CS had the lowest fiber content (20.45%) and BLB the highest, at 31.5%. Between the varieties in the post hoc analysis (Table S2), BLB differed significantly from CRM, CS, F17, F32, and FRM (p-values: 0.003, 0.003, 0.011, 0.049, and 0.013, respectively) and marginally from F75. Additionally, CRM differed from S27, S70, and TGR (0.007, 0.011, and 0.044), F17 differed from S27 and S70 (0.027 and 0.044), F32 differed marginally from S27, and CS differed from S27, S70, and TGR (p-values: 0.004, 0.007, 0.029, and 0.013, respectively) and marginally from KCD and U31.

S27 yielded the most fiber (median 28.1%) and, as in the previous year, CS yielded the least, at 19.08%, in 2021. In both 2022 and 2023, KMP was the most fiber-productive variety, with yields of 37.4% and 34.6%, respectively, whereas TBR was the least productive, with yields of 17.5% and 16.4%, respectively. Specifically, in 2022, KMP differed significantly from CS, F32, and TBR (0.048, 0.048, and 0.018), and marginally from F17 and FRM (Supplementary Table S2), while TBR differed significantly from KMP (p = 0.018).

3.3. Weight of Thousand Seeds (g)

Figure 4 presents the median values for the weight of 1000 seeds for all years and tested varieties. Overall, statistically significant differences were observed in all years except 2019. The variety FIN, a seed-oriented variety, which was tested only in 2017, had the highest seed weight of 9.75 g and differed, to a statistically significant extent, from almost all varieties (Supplementary Table S3). In 2017, F17 had the second highest median seed weight of 7 g, while S27 had the lowest, at 5.5 g, with significant differences between these two varieties (p-value: 0.09). F17 also had the heaviest seeds in 2018, weighing 10.55 g, whereas BLB had the lowest median value of 6.75g, with a p-value of 0.001 between these varieties. The seed weight of F17 differed, in the post hoc analysis, from S27 and TGR (p-values: 0.027 and 0.099, respectively), and BLB differed from F32 and F75 (p-values: 0.027 and 0.042) and slightly from TGR.

In 2019, BLB again had the lowest seed weight (7 g), while F75 had the highest, at 10.75 g. The variety F75 had also the heaviest seed weight in the years 2021 (12 g) and 2023 (12.85 g), while, in the years 2020 and 2022, it was in second position, measuring 9.5 g and 13.5 g, respectively.

S27 seeds (6 g) were the lightest in 2020 and TGR (10 g) were the heaviest. On the contrary, in 2021, TGR had the lowest seed weight (7 g), while, as mentioned before, F75 had the heaviest seed weight (p-value: 0.045). In 2020, in the post hoc analysis, the weight of S27 seeds differed (Table S3), to a statistically significant extent, from TGR (p-value: 0.018) and slightly from F75, while TGR differed from BLB. The post hoc analysis of 2021 data showed marginal differences between BLB, F32, and F75 and between F75 and TGR.

U31 was the variety with the heaviest seed weight in 2022 (13.75 g), while S27 had the lightest seeds (8.75 g). S27 differed, to a statistically significant extent, not only from U31 (0.002), but also from TGR, FRM, F75, and F17 (p-values: 0.064, 0.088, 0.002, and 0.016). On the other hand, U31 also differed from F32 and BLB (p-values: 0.019 and 0.02, respectively) and BLB from KCD (p-value: 0.002) and from F75 (p-value: 0.020).

In 2023, the heaviest seeds of F75 (12.85 g) differed significantly, not only from S70 (p-value: 0.003), which, at a weight of 7.45 g per 1000 seeds, was the variety with the lightest seeds, but also from CS, TGR, and U31 (0.011, 0.083, and 0.014, respectively).

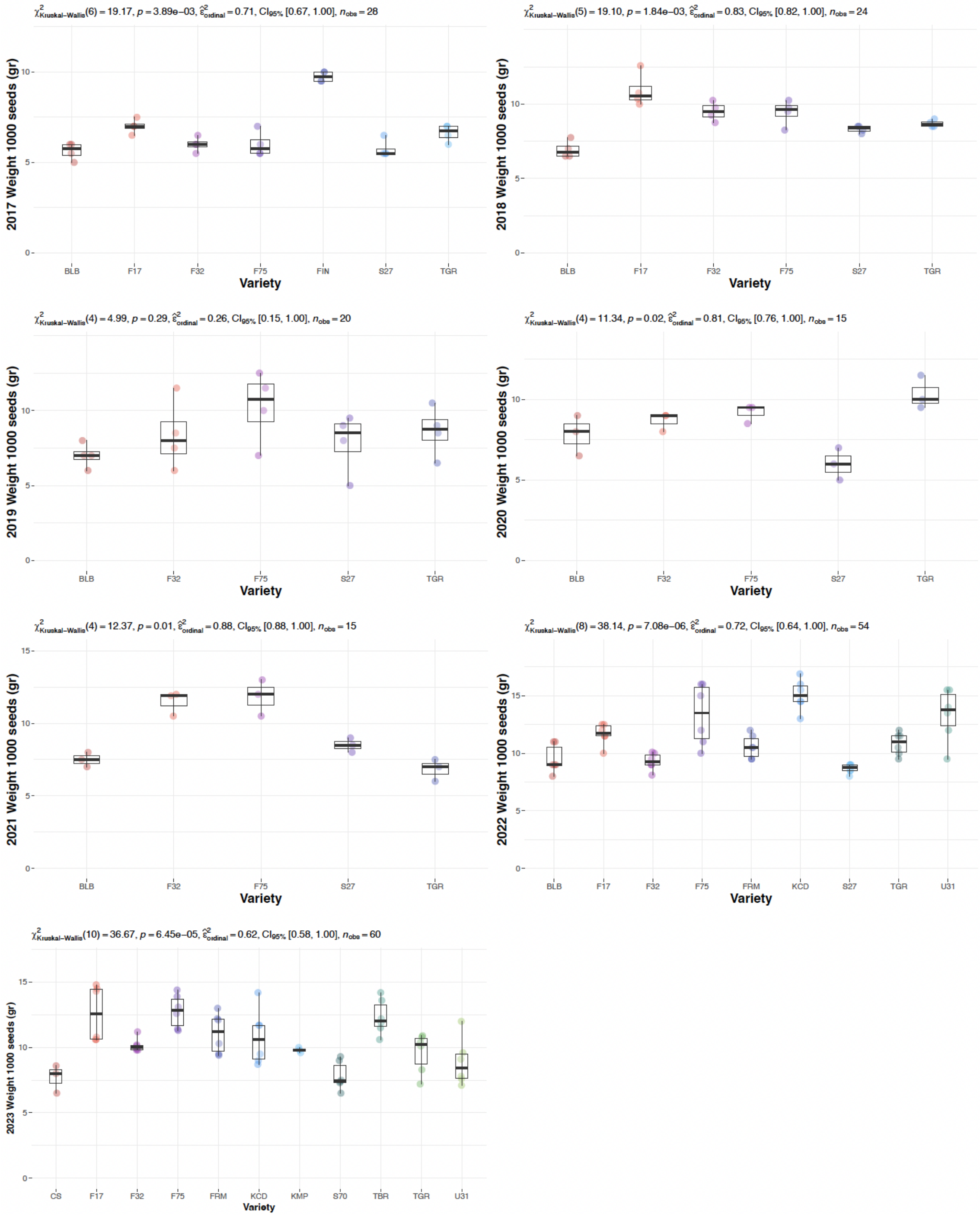

Figure 4. Weight of 1000 seeds (g) of the tested varieties in 2017–2023. The varieties' names are abbreviated as follows: Bialobrzeskie: BLB; Carmagnola: CRM; Carmagnola Selezionate: CS; Fedora 17: F17; Felina 32: F32; Ferimon: FRM; Finola: FIN; Futura 75: F75; KC Dora: KCD; Kompolti: KMP; Santhica 27: S27; Santhica 70: S70; Tiborszallasi: TBR; Tygra: TGR; Uso 31: U31.

4. Discussion

Industrial hemp cultivation has gained global recognition as a highly successful commercial crop due to its significant carbon-sequestering properties, versatility in end-use products, and high biomass production [8]. Aiming to build upon this fact, the trial herein, which was conducted in Greece from 2017 to 2023, evaluated fourteen varieties and demonstrated that not only could the dioecious varieties CRM, CS, TBR, and KMP be successfully cultivated for biomass production but also the monoecious varieties BLB, F17, F32, FRM, F75, KCD, S27, S70, TGR, and U31 could be effectively grown. Although the highest fresh biomass yield was obtained from the TBR variety, which reached 73.0 t ha^{-1} in two years of experimentation (2022 and 2023), KMP, with 55.0 t ha^{-1}, CS, with a total of 48.8 t ha^{-1}, and CRM, with 35.9 t ha^{-1}, were also highly productive (Supplementary Table S4). According to [12], in Belgium, CRM also produced more biomass than the tested monoecious varieties, and, in Virginia, USA [13], a higher biomass production of Carmagnola was also observed, in comparison with F17 and F75, mainly because late flowering varieties, like Carmagnola, result in the highest stem biomass but a lower grain yield.

Among the monoecious varieties, according to the data (Figure 2, Supplementary Table S4), it can be concluded that F75 demonstrated an exceptional biomass yield, ranging from 21.5 t ha^{-1} in 2019 to 52.5 t ha^{-1} in 2022, making it one of the highest-yielding and best-adapted varieties to Greek agroclimatic conditions. The variety Futura 75 also achieved the highest above-ground biomass in Latvia, where the biomass yields of ten varieties varied from 36 to 54 t ha^{-1} in 2011 and from 48 to 75 t ha^{-1} in 2012, depending on the variety [14]. Additionally, a high total biomass yield for variety Futura 75 under Mediterranean conditions in Greece has been previously reported [15] under four nitrogen fertilizer rates. Specifically, biomass yields ranged from 25.4 Mg/ha in the control variety Bialobrzeskie to 187.7 Mg/ha at the highest fertilization dose in Futura 75.

Moreover, in Lithuania [16], it has been reported that the biomass yield of fresh hemp in 2014, which included stems, leaves, inflorescences, and seeds, was sufficiently high (30.2–48.2 t ha^{-1}) and was affected mainly by seed rate and variety. Compared to variety USO 31, which had a yield of 33.3 t ha^{-1}, the variety Bialobrzeskie had a higher yield of 43.7 t ha^{-1}. The current experiment in Greece (Figure 2) also reported that the U31 variety was among the four varieties with the lowest biomass yields. While, for most of the cultivation years (2017, 2019, 2020, and 2021), BLB was in the top five varieties for biomass yield, in 2018, it had the lowest biomass production, measuring 27.5 t ha^{-1}, and, in 2022, with 28.7 t ha^{-1}, it was next to last. The low biomass yields in the years 2018 and 2022 are in accordance with previous results [15] while, in Romania [17], the variability in fresh biomass yield among different varieties across multiple years was underlined, reflecting the importance of variety selection in optimizing biomass production.

On the other hand, other results [18] showed that, for hemp cultivated under Mediterranean conditions in Italy, the total hemp biomass ranged from 28.82 t ha^{-1} to 31.21 t ha^{-1}, which are in accordance with the lowest values of each year in the experiment presented in Figure 2. The total biomass of six hemp varieties cultivated in Italy varied from 32.5 t ha^{-1} to 45.5 t ha^{-1} [19], indicating that the cultivation of varieties bred in cooler northern environments resulted in completely different productivity levels in southern environments. The variability of biomass yield can be explained by the fact that hemp has adapted to a wide range of climates and latitudes and can thus possess large variability in its sensitivity to day length [20], because most hemp varieties are photoperiodic. The timing of the transition from vegetative growth to flowering is key for a high yield and an acceptable fiber quality for hemp [21].

A high fiber content is desirable because fiber has a higher economic value than the woody core [22]; the mean fiber content in this study ranged from 15.6% (CRM variety, 2019) to 37.4% (KMP variety, 2022). The fiber content of these 14 hemp varieties ranged from 21.0% to 43.0% in four different countries [23]. The results (Supplementary Table S5) showed that, for the tested varieties, their fiber contents were relatively stable over the years, in agreement with previous studies [24,25], indicating that fiber content is under strong genetic control [26]. The stem fiber content can be considered a genotypic parameter, because the difference in fiber contents between genotypes was not influenced by environmental conditions and harvesting times [27].

The results of Figure 3 showed that, although the highest biomass production was achieved by the TBR variety in the years 2022 and 2023, and although Tiborszallasi was able to produce a suitably high biomass [28], the median fiber contents of TBR were the lowest, at 17.5 and 16.4%, respectively. The CS variety was the least fiber-productive variety in the years 2018, 2019, and 2020 (21.3%, 15.8%, and 20.45%, respectively), followed by CRM, as a consequence of their long vegetative phases, as also reported in [23]. In Belgium [12], it was mentioned that the CRM fiber content was lower, in comparison to the other tested varieties, in contrast to its high biomass productivity. This trend of dioecious varieties is reversed for KMP, which is the leader in fiber production, reaching 36% (Supplementary Table S5). Generally, Kompolti, with a fiber content of 30–32% [29], is considered the leader and confirms that late-flowering varieties with extended vegetative growth are good for fiber production [13].

Among the monoecious varieties (Figure 3), the fiber content ranged from 19.8% (F32, 2022) to 31.5% for the variety BLB in 2020. The varieties Bialobrzeskie, Santhica 27, and Santhica 70 provided the highest fiber contents (27.7%, 27.3%, and 27.1%, respectively, as averaged across the years), similarly to [16], wherein it was reported that the fiber content of the variety Bialobrzeskie, cultivated in Lithuania, ranged from 25.1% to 30.8%. The results for the F75 variety, with a mean of medians of 24.6%, and for FRM, with 24.4%, are in accordance with the data in [30], due to the fact that fiber yield did not generally increase with the duration of the vegetation period.

Varieties that show early flowering are better suited for seed production [13] because the transition to flowering hinders vegetative growth and redirects resources to reproductive growth; the early–medium and medium monoecious varieties showed a better stability in grain production across the years than the dioecious varieties [31].

Referring to the 1000-seed weight of dioecious varieties (Supplementary Table S6), in most of the experimentation years, the late maturity of the seeds resulted in no production of seeds and no values, which was in contrast to the monoecious varieties, the 1000-seed weights of which ranged from 5.5 g for S27 in 2017 to 15 g for KCD in 2022. Among the monoecious varieties, KCD, with a 1000-seed weight of 12.8 g, followed by U31 with an average of 11.1 g, seemed to produce the heavier seeds. U31 is a seed-oriented Ukrainian variety with a shorter growth cycle [32], which seemed to adapt well to different agro-climatic conditions. Similarly, it was reported [30] that late-maturing varieties produced consistently lower seed yields than the early-maturing varieties. The greater 1000-seed weight of F17 (10.5 g) compared to F32 and BLB was also mentioned in [13], where the 1000-seed weights for the varieties Bialobrzeskie, Fedora 17, and Felina 32 were 12.1 g, 14.9 g, and 12.6 g, respectively. Under Greek conditions, in three years (2016–2018), Futura 75 and Fedora 17 had 1000-seed weights of 7.9 and 8.3 g, respectively [6], and the same trend was observed in the presented experimental data for all seven years, wherein F75 exhibited a mean of medians of 10.6 g and F17 of 10.5 (Supplementary Table S5).

All of the industrial hemp varieties grown in this study contained < 0.3% (w/w) Δ9-tetrahydrocannabinol (THC), which is the permitted level for cultivation, according to EU legislation [8].

These findings underline the variability between different varieties across multiple years, reflecting the importance of further research and analysis in elucidating the underlying factors contributing to these observed differences and in informing strategic decision-making in agricultural practices. This would be important for the possible end uses of the genotypes and for supporting farmers with selecting the correct variety for their final crop purpose and agronomic environment.

5. Conclusions

The trials conducted in Greece from 2017 to 2023 on fourteen registered hemp varieties revealed significant variations in biomass, fiber, and seed production across different years and among the varieties. Under the specific climatic conditions of Greece, monoecious varieties demonstrated strong potential for biomass production, with the F75 variety showing particularly high yields. While dioecious varieties can be cultivated for biomass, they generally do not produce high fiber yields, with the notable exception of the superior Kompolti variety. The highest fiber yield among the tested varieties was observed in the Bialobrzeskie variety. For seed production, early-flowering varieties proved to be most effective, with the KC Dora variety producing the heaviest seeds. These findings underscore the importance of selecting hemp varieties that are well-adapted to local environmental conditions to optimize both vegetative growth and flowering. The current availability of diverse hemp varieties supports multipurpose cultivation, thereby enhancing the sustainability of hemp-farming practices.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy14091946/s1. Supplementary Table S1: Post hoc analysis of biomass (t/ha) for the experimentation years 2017–2023. Each line corresponds to a pairwise comparison. The asterisk corresponds to p-values < 0.05, the dot to 0.05 < p-values < 0.10, and NS stands for non-significant (p-values > 0.10). Supplementary Table S2: Post hoc analysis of fibers (%) for the experimentation years 2017–2023. Each line corresponds to a pairwise comparison. The asterisk corresponds to p-values < 0.05, the dot to 0.05 < p-values < 0.10, and NS stands for non-significant (p-values > 0.10). Supplementary Table S3: Post hoc analysis of 1000-seed weight (g) for the experimentation years 2017–2023. Each line corresponds to a pairwise comparison. The asterisk corresponds to p-values < 0.05, the dot to 0.05 < p-values < 0.10, and NS stands for non-significant (p-values > 0.10). Supplementary Table S4: Medians of fresh biomass (t/ha) per year/variety along with means of the medians across each year/variety. Supplementary Table S5: Medians of fibers (%) per year/variety along with means of the medians across each year/variety. Supplementary Table S6: Medians of 1000-seed weights (g) per year/variety along with means of the medians across each year/variety.

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References

1. Nava, V.; Albergamo, A.; Bartolomeo, G.; Rando, R.; Litrenta, F.; Lo Vecchio, G.; Giorgianni, M.C.; Cicero, N. Monitoring Cannabinoids and the Safety of the Trace Element Profile of Light *Cannabis sativa* L. from Different Varieties and Geographical Origin. *Toxics* **2022**, *10*, 758. [CrossRef] [PubMed]
2. Schluttenhofer, C.; Yuan, L. Challenges towards Revitalizing Hemp: A Multifaceted Crop. *Trends Plant Sci.* **2017**, *22*, 917–929. [CrossRef]
3. Kaur, G.; Kander, R. The sustainability of industrial hemp: A literature review of its economic, environmental, and Social Sustainability. *Sustainability* **2023**, *15*, 6457. [CrossRef]
4. Baldini, M.; Ferfuia, C.; Zuliani, F.; Danuso, F. Suitability assessment of different hemp (*Cannabis sativa* L.) varieties to the cultivation environment. *Ind. Crops Prod.* **2020**, *143*, 111860. [CrossRef]
5. Sikora, V.; Berenji, J.; Latković, D. Influence of agroclimatic conditions on content of main cannabinoids in industrial hemp (*Cannabis sativa* L.). *Genetica* **2011**, *43*, 449–456. [CrossRef]
6. Tsaliki, E.; Kalivas, A.; Jankauskiene, Z.; Irakli, M.; Cook, C.; Grigoriadis, I.; Panoras, I.; Vasilakoglou, I.; Dimas, K. Fibre and Seed Productivity of Industrial Hemp (*Cannabis sativa* L.) Varieties under Mediterranean Conditions. *Agronomy* **2021**, *11*, 171. [CrossRef]
7. Amaducci, S.; Scordia, D.; Liu, F.H.; Zhang, Q.; Guo, H.; Testa, G. Key cultivation techniques for hemp in Europe and China. *Ind. Crops Prod.* **2014**, *68*, 2–16. [CrossRef]
8. Tsaliki, E.; Kalivas, A. Hemp Crop Opportunities. *Ann. Agric. Crop Sci.* **2024**, *9*, 1154.
9. Kołodziej, J.; Pudełko, K.; Mańkowski, J. Energy and Biomass Yield of Industrial Hemp (*Cannabis sativa* L.) as Influenced by Seeding Rate and Harvest Time in Polish Agro-Climatic Conditions. *J. Nat. Fibers* **2023**, *20*, 2159609. [CrossRef]
10. Mediavilla, V.; Jonquera, M.; Schmid-Slembrouck, I.; Soldati, A. A decimal code for growth stages of hemp (*Cannabis sativa* L.). *J. Int. Hemp Assoc.* **1998**, *5*, 65–74.
11. Patil, I. Visualizations with statistical details: The 'ggstatsplot' approach. *J. Open Source Softw.* **2021**, *6*, 3167. [CrossRef]
12. Vandepitte, K.; Vasile, S.; Vermeire, S.; Vanderhoeven, M.; Van der Borght, W.; Latré, J.; Roch, V. Hemp (*Cannabis sativa* L.) for high-value textile applications: The effective long fiber yield and quality of different hemp varieties, processed using industrial flax equipment. *Ind. Crops Prod.* **2020**, *158*, 112969. [CrossRef]

13. Rahemi, A.; Dhakal, R.; Temu, V.W.; Rutto, L.; Kering, M.K. Performance of Different-Use Type Industrial Hemp Cultivars under Mid-Atlantic Region Conditions. *Agronomy* **2021**, *11*, 2321. [CrossRef]
14. Sausserde, R.; Adamovics, A. Industrial hemp for biomass production. *J. Agric. Eng.* **2013**, *44*, s2. [CrossRef]
15. Papastylianou, P.; Kakabouki, I.; Travlos, I. Effect of nitrogen fertilization on growth and yield of industrial hemp (*Cannabis sativa* L.). *Not. Bot. Horti Agrobot.* **2018**, *46*, 197–201. [CrossRef]
16. Jankauskiene, Z.; Gruzdeviene, E.; Ivanovs, S.; Maumevicius, E. Screening hemp (*Cannabis sativa* L.) biomass and chemical composition as influenced by seed rate and genotype. *Proc. Eng. R. Dev.* **2017**, *16*, 317–322. [CrossRef]
17. Panda, A.O.; Buzna, C.C.; Cojocariu, C.; Cotuna, O.; Pop, G. Expression of the productivity of some varieties of dioic hemp (*Cannabis sativa* L.) in the conditions of the Banat plain. *Life Sci. Sustain. Dev.* **2021**, *2*, 104–111. [CrossRef]
18. Cappelletto, P.; Brizzi, M.; Mongardini, F.; Barberi, B.; Sannibale, M.; Nenci, G.; Poli, M.; Corsi, G.; Grassi, G.; Pasini, P. Italy-grown hemp: Yield, composition and cannabinoid content. *Ind. Crops Prod.* **2001**, *13*, 101–113. [CrossRef]
19. Di Bari, V.; Campi, P.; Colucci, R.; Mastrorilli, M. Potential productivity of fibre hemp in southern Europe. *Euphytica* **2004**, *140*, 25–32. [CrossRef]
20. Zhang, M.; Anderson, S.L.; Brym, Z.T.; Pearson, B.J. Photoperiodic Flowering Response of Essential Oil, Grain, and Fiber Hemp (*Cannabis sativa* L.) Cultivars. *Front. Plant Sci.* **2021**, *12*, 694153. [CrossRef]
21. Amaducci, S.; Colauzzi, M.; Bellocchi, G.; Cosentino, S.L.; Pahkala, K.; Stomph, T.J.; Westerhuis, W.; Zatta, A.; Venturi, G. Evaluation of a phenological model for strategic decisions for hemp (*Cannabis sativa* L.) biomass production across European sites. *Ind. Crops Prod.* **2012**, *37*, 100–110. [CrossRef]
22. Carus, M.; Karst, S.; Kauffmann, A.; Hobson, J.; Bertucelli, S. The european hemp industry: Cultivation, processing and applications for fibres, shives and seeds. *Eur. Ind. Hemp Assoc.* **2013**, 1–9. Available online: https://renewable-carbon.eu/publications/download-confirmation-page/?somdn_rrpage=somdn_rrpage&somdn_rrtdid=244957&somdn_rrdkey=MjQ0OTU3&somdn_rrskey=MTcyNDgzNDAyNA=&somdn_rrpkey=MjEzMA=&somdn_rrukey=MA=&somdn_rrtype=cmVkaXJlY3Q (accessed on 3 June 2024).
23. Tang, K.; Struik, P.C.; Yin, X.; Thouminot, C.; Bjelkova, M.; Stramkale, V. Comparing hemp (*Cannabis sativa* L.) cultivars for dual-purpose production under contrasting environments. *Ind. Crops Prod.* **2016**, *87*, 33–46. [CrossRef]
24. Amaducci, S.; Zatta, A.; Pelatti, F.; Venturi, G. Influence of agronomic factors on yield and quality of hemp (*Cannabis sativa* L.) fibre and implication for an innovative production system. *Field Crops Res.* **2008**, *107*, 161–169. [CrossRef]
25. Sankari, H.S. Comparison of bast fibre yield and mechanical fibre properties of hemp (*Cannabis sativa* L.) cultivars. *Ind. Crops Prod.* **2000**, *11*, 73–84. [CrossRef]
26. Petit, J.; Salentijn, E.M.J.; Paulo, M.J.; Denneboom, C.; van Loo, E.N.; Trindade, L.M. Elucidating the Genetic Architecture of Fiber Quality in Hemp (*Cannabis sativa* L.) Using a Genome-Wide Association Study. *Front. Genet.* **2020**, *11*, 566314. [CrossRef] [PubMed]
27. Westerhuis, W.; Amaducci, S.; Struik, P.C.; Zatta, A.; Van Dam, J.E.; Stomph, T.J. Sowing density and harvest time affect fibre content in hemp (*Cannabis sativa*) through their effects on stem weight. *Ann. Appl. Biol.* **2009**, *155*, 225–244. [CrossRef]
28. Michal, P.; Svehla, P.; Malik, M.; Kaplan, L.; Hanc, A.; Tlustos, P. Production of biogas from the industrial hemp variety, Tiborszállási. *Environ. Technol. Innov.* **2023**, *31*, 103185. [CrossRef]
29. Karinaplant.hu. Available online: https://karinaplant.hu/en/hungarian-hemp-breeding-is-world-famous/ (accessed on 3 June 2024).
30. Höppner, F.; Menge-Hartmann, U. Yield and quality of fibre and oil of fourteen hemp cultivars in Northern Germany at two harvest dates. *Landbauforsch. Völkenrode* **2007**, *3*, 219–232.
31. Baldini, M.; Ferfuia, C.; Piani, B.; Sepulcri, A.; Dorigo, G.; Zuliani, F.; Danuso, F.; Cattivello, C. The Performance and Potentiality of Monoecious Hemp (*Cannabis sativa* L.) Cultivars as a Multipurpose Crop. *Agronomy* **2018**, *8*, 162. [CrossRef]
32. De Vos, B.; Fernandez De Souza, M.; Michels, E.; Meers, E. Industrial hemp (*Cannabis sativa* L.) field cultivation in a phytoattenuation strategy and valorization potential of the fibers for textile production. *Environ. Sci. Pollut. Res.* **2023**, *30*, 41665–41681. [CrossRef] [PubMed]