Industrial Hemp Variety Trials

Results from The Katherine Research Station trial site

for the 2024 growing season

by Shah Nawaz

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Foreword

AgriFutures Australia has recognised the potential for significant growth in the industrial hemp (*Cannabis sativa* L.) sector due to its wide range of sustainable applications and uses. The benefits associated with the oil profile of hemp grain, which has one of the best Omega 3:6 ratios of any plant-based oil are a key factor in the potential of this crop. Against this backdrop, the AgriFutures Australia Emerging Industries Program has invested in a series of variety trials to understand the crop's performance across Australian growing environments.

The aim of the Industrial Hemp Variety Trials (IHVT) program is to provide Australian hemp growers with essential data by evaluating grain and dual-purpose hemp varieties appropriate for diverse growing regions throughout Australia. To accomplish this, trial sites have been set up in multiple locations across Australia, encompassing the Northern Territory, South Australia (2), Tasmania, Victoria, Western Australia (2), Queensland and New South Wales.

The 2024 Katherine Research Station (Northern Territory) trial comprised eight varieties (Bama, CRS-1, Han Cold, Han NE, Ruby, Yuma, Ferimon-12 and Muka 76) and three times of sowing (TOS), with four replicates of each treatment (except TOS 1, which had only two replications due to irrigation constraints at the trial site). TOS 1 was sown on 04 April 2024, TOS 2 on 30 April and TOS 3 on 30 May.

Crop establishment was poor for all sowing times with all varieties failing to achieve desired plants/m^2 (except Ruby at TOS 3). Han NE produced the highest grain yield, averaging 1.2122 t/ha across three sowing times, followed by Bama (1.0540 t/ha) and Han Cold (1.0185 t/ha) while Muka 76 produced the lowest yield at an average of 0.4962 t/ha across all sowing times.

Time of sowing 1 recorded the highest plant height of 138.2 cm averaged across all genotypes. Han Cold and Han NE were the tallest varieties, 138.45 cm and 134.45 cm respectively, whereas CRS-1 was the shortest variety with 40.90 cm averaged across sowing times. The highest biomass producing varieties were Yuma and Han Cold, averaging dry matter of 4.690 t/ha and 4.250 t/ha respectively, while CRS-1 yielded the lowest dry matter of 0.961 t/ha across all times of sowing. Generally, TOS 1 recorded higher grain and dry matter yields than the other sowing times in the 2024 season.

Han Cold and Han NE recorded the highest 1000 grain weight and Ruby produced the highest bulk density, protein content and oil content across all sowing times. Ferimon 12 produced the lowest 1000 grain weight, Bama was lowest in protein and oil content and Muka 76 had the lowest bulk density across all sowing times.

The 2024 trial results from Katherine Research Station site have been produced as part of AgriFutures Australia's Emerging Industries Program, which focuses on new and emerging industries with high growth potential. Emerging animal and plant industries play an important part in the Australian agricultural landscape. They contribute to the national economy and are key to meeting changing global food and fibre demands. Most of AgriFutures Australia's publications are available for viewing, free download or purchase online at www.agrifutures.com.au/knowledge-hub/.

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Shah Nawaz is a Research Scientist working with the Department of Agriculture and Fisheries (DAF) of the Northern Territory Government.

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- Midlands Seed
- Hemp Farms Australia
- The Hemp Corporation

The following DAF staff assisted with trial site management and data collection: -

- Edward Mwando
- Simon Ong
- Staci Stanley
- Katie Gamble

The national Industrial Hemp Variety Trials (IHVT) program is coordinated by Mark Skewes from the South Australian Research and Development Institute (SARDI), while John Muir, Hemp Agronomist provides agronomic and technical advice on trial operations.

Abbreviations

AST	Analytical Services Tasmania
DAS	Days after Sowing
DAF	Department of Agriculture and Fisheries
IHVT	Industrial Hemp Variety Trials
KRS	Katherine Research Station
NT	Northern Territory
SE	Standard Error
THC	Tetrahydrocannabinol
TOS	Time of Sowing
NTG	Northern Territory Government

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Executive summary

Industrial hemp is utilised in a variety of non-psychoactive products, including food, building materials, plastics, pulp and paper, textiles, bioplastics, pharmaceuticals, cosmetics, and animal feed. In 2017, Australian legislation (governed by Food Standards Australia New Zealand) was amended to permit the domestic sale of hemp for human consumption (seed and oil). This led to the rapid growth of the hemp industry in Australia. Despite this, the Australian hemp industry possesses little knowledge on selecting the best-adapted varieties to local growing conditions. Further, licensing and related administrative costs may limit potential growers from entering the hemp industry. To lessen these uncertainties and to give potential producers confidence, accurate information on local hemp cultivation is required. In turn, this may encourage industry expansion.

The *Australian Industrial Hemp Strategic RD&E Plan (2022-2027)* prioritises the establishment of nationally coordinated Industrial Hemp Variety Trials (IHVT) covering current and future production environments (Jefferies, 2022). Co-funded by AgriFutures Australia, in partnership with participating state and territory government agencies, the program concentrates on the production of hemp seed (grain) suitable for human consumption, with the intent of identifying suitable varieties to assist growers in cultivation.

This report presents the findings from the trial conducted in 2024 at Katherine Research Station (KRS), Northern Territory (NT). The performance of eight industrial hemp varieties were compared at three times of sowing (TOS 1, TOS 2 and TOS 3), with four replicates at each TOS (except TOS 1 which has only two replications due to irrigation constraints).

The 2024 trial was impacted by low quality seed, resulting in poor germination and seedling vigour. Plant density was measured three weeks after sowing and at harvest. The proportion of male, female and hermaphrodite plants was determined at flowering. Flower head samples were collected during peak female flowering for tetrahydrocannabinol (THC) testing, and plant height was measured at harvest.

Grain harvest was undertaken when 70% hard and/or dry brown seeds were observed in flower heads. Plants from a 2 m long x 2 central rows area were hand-harvested from each plot as a representative sample of each of variety, for all replicates of each variety at each time of sowing. Total above-ground dry biomass, grain yield and 1000 grain weight were measured after drying. Grain bulk density, oil and protein content were obtained from samples sent to Analytical Services Tasmania (AST).

Multi-season comparison of trial data from three seasons was performed to provide variety recommendations applicable to a sowing time between March and May.

Across sowing times in 2024 Bama, Han Cold, Han NE and Yuma were late maturing varieties (> 100 days to maturity), Ruby was mid to late maturing (90-100 days to maturity), and CRS-1, Ferimon-12 and Muka 76 were early maturing varieties (< 80 days to maturity). THC content in the flower heads (at peak flowering) was below 1% for all varieties, at all sowing times.

Poor crop establishment at all sowing times and varieties, averaging 71 plants/m^2, failed to achieve the desired plant population of 150 plants/m^2 (except Ruby in TOS 3). Poor crop establishment may be associated with the high temperature experienced during the sowing period and low viability of seeds.

Han Cold (138.45 cm), Han NE (134.45 cm) and Bama (126.22 cm) were the tallest varieties. Yuma and Han Cold both produced > 4 t/ha of dry matter. The analysis showed a strong variety effect and a significant variety by TOS interaction on grain yield and quality, apart from 1000-grain weight.

Han NE produced the highest grain yield of 1.47 t/ha, while Han Cold had the greatest 1000 grain weight of 25.90 g. Ruby was the best variety for grain quality parameters of protein and oil percentage.

All early maturing varieties performed poorly for grain yield, but the grain quality was better compared to late maturing varieties.

Multi-season analysis indicated that Han Cold and Yuma were the highest grain producing varieties at an average of 1.68 t/h, whereas Ruby was the superior variety in terms of grain quality (protein and oil percentages in grain). Henola's performance for a number of parameters such as plant height, dry matter production, 1000-grain weight, and grain yield was poorest and hence this variety ranked the lowest among the varieties trialled.

Findings from the multi-season IHVT will benefit all stakeholders along the hemp production value chain with selecting varieties that are suitable for the Northern Australian environment, and in determining the best time to sow industrial hemp.

Further research is recommended to further evaluate potential varieties identified in the multi-season trials of the program to address other agronomic issues, such as the impact of plant nutrition and water on yield and quality of hemp products, costs associated with plant production and the impact of temperature on hemp germination. Some of these additional researchable issues are being addressed by the AgriFutures Industrial Hemp Research Program.

Introduction

Industrial hemp is a low-tetrahydrocannabinol (THC) type of the *Cannabis sativa* L. crop and has a long history of utilisation by mankind for textiles and food. At present, industrial hemp has a wide range of applications and is predominately grown for fibre and seed.

Australian legislation was amended in 2017 permitting hemp grain to be sold for human consumption (seed and oil), which has led to the rapid growth of the hemp industry in Australia. In addition, all states and the Northern Territory now have legislation in place for industrial hemp production.

Despite the growing demand for hemp products, hemp production in Australia is still in its infancy and hence the need for ongoing research including screening of varieties suitable for different growing regions and the best sowing time to broaden future production. Considering this, AgriFutures Australia developed the *Australian Industrial Hemp Strategic RD&E Plan (2022-2027)(* https://agrifutures.com.au/product/australian-industrial-hemp-strategic-rde-plan/*)* with the vision that, "research, development and extension will enable the gross value of Australian industrial hemp to exceed $10 million per annum by 2026" (Jefferies, 2022).

The highest priorities for industry as contained in the Strategic RD&E Plan include:

- Establishing a nationally coordinated industrial hemp variety trial system that covers the current and future major production environments.
- Establishing an effective process to communicate variety trial results in a timely and professional manner.
- Establishing a clear understanding of the variety information needs of Australian industrial hemp growers.

The Industrial Hemp Variety Trials (IHVT) program, co-funded by AgriFutures Australia and participating state and territory government agencies is a step towards achieving the priorities of the Strategic Plan. The program screens varieties for suitability in different production regions with the aim of providing Australian hemp growers with independent and consistent information about the performance of industrial hemp seed varieties. The trials are conducted with both monoecious and dioecious commercial varieties suited for grain or dual-purpose production (i.e., grain and fibre).

The trials are executed by participating trial providers following the approved IHVT protocols. The protocols provide technical detail on how the trials will be conducted to ensure common standards and practices. The trial coordinator, Mark Skewes from the South Australian Research and Development Institute (SARDI), works with the respective trial providers to implement the trials. Agronomic guidance is provided by hemp agronomist John Muir.

The NTG, Department of Agriculture and Fisheries (DAF) is the co-funder and trial provider in the NT. The trials are conducted at Katherine Research Station (KRS), about 320 km south of Darwin (Figure 1). This report provides information about the performance of industrial hemp varieties (Table 1) evaluated for their suitability to grow in the Katherine region, planted at different sowing times. Conducting this research in the NT is aimed at generating grower interest for industry expansion in the Top End.

Objectives

The primary objective of the Industrial Hemp Variety Trials (IHVT) is the evaluation of varieties for industrial hemp grain production at a network of trial sites contracted by AgriFutures Australia.

As well as trialling a range of varieties, different sowing times are also being evaluated to inform growers as to the best time of year to grow industrial hemp under localised climate zones, agronomic practices and seasonal conditions.

Publication of IHVT results will provide Australian hemp growers with independent information about the performance of industrial hemp varieties in producing grain.

Methodology and data analysis

Katherine Research Station (KRS), NT, is located in the Northern Climatic Zone, and was already an established trial site for the 2022 and 2023 seasons of the IHVT. The site is located at 14^{0}27’ S latitude, and 132^{0}18’ E longitude (Figure 1). The hemp variety trial was conducted inside a bird exclusion cage, continuously for the 3 years of the project. The Tippera soils of the KRS are a red earth or clay loamy red Kandosol that are often referred to as red, yellow and brown earths. These massive and earthy soils are important in agricultural and horticultural production. Occurring throughout the NT, Kandosols are widespread across the Top End, Sturt Plateau, Tennant Creek and Central Australia regions (Appendix 1 – Table A1.1 and Figure A1.1) (Department of Land Resource Management, 2021).

Figure 1: Location of Katherine Research Station the 2024 industrial hemp varietal trial in the Northen Territory.

Eight industrial hemp varieties were planted in the IHVT 2024 season (Table 1). The performance of all varieties was evaluated in three Time of Sowing (TOS) treatments, with sowing dates: 04/04/2024 (TOS 1), 30/04/2024 (TOS 2) and 30/05/2024 (TOS 3). Each trial plot was 5 m long and 1.5 m wide, with seeds placed 1.5-2 cm deep in six rows spaced 25 cm apart using a precision cone seeder.

Table 1: Varieties trialled at KRS in 2024 (information provided by seed suppliers).

Variety	Supplier	Country of Origin	Type	Primary use	Reported THC (%)
Bama	The Hemp Corporation	China	Dioecious	Dual purpose	<0.2
CRS-1	Midlands Seed	Canada	Dioecious	Grain	0.03
Han Cold	The Hemp Corporation	China	Dioecious	Dual purpose	<0.2
Han NE	The Hemp Corporation	China	Dioecious	Dual purpose	<0.3
Ruby	Hemp Farms Australia	Australia	Dioecious	Dual purpose	0.15
Yuma	The Hemp Corporation	China	Dioecious	Dual purpose	<0.3
Ferimon-12	Midlands Seed	France	Monoecious	Dual purpose	<0.02
Muka 76	Midlands Seed	France	Monoecious	Dual purpose	<0.2

Varieties were sown in a Randomized Complete Block Design (RCBD) with four replications (except TOS 1, which had only two replications due to irrigation constraint at the trial site). The target plant density was 150 plants/m^2 and sowing rate for each variety was calculated using the germination percentage obtained from each batch of seed (Appendix 2). Before sowing, all seeds were treated with fungicide (Thiram) at 5g of diluted mixture per kg of seed to protect seeds from soil borne diseases.

No cover crops were established due to high rainfall experienced prior to sowing the cover crop. The significant rainfall occurred in the month of January, making it impossible to access the paddock as it was too wet. Consequently, we couldn't sow the cover crop as initially intended. The seedbed was cultivated prior to all TOS. The trial site was cultivated with chisel plough to break up compacted soil crust, then rotary hoed to create a fine seedbed and harrowed to incorporate fertilizer prior to sowing. The plots for the 3 TOS were given an overhead pre-irrigation to field capacity 2 - 3 days before sowing using a permanent irrigation system with 2.5 m tall steel risers with sprinklers (spaced at 8 m × 8 m) and connected to a solenoid timer system. Another irrigation was applied immediately after sowing, and subsequent irrigation scheduling was determined according to crop growth stage and weather conditions. Temperatures during the three sowing times at the trial site is shown in Figure 2.

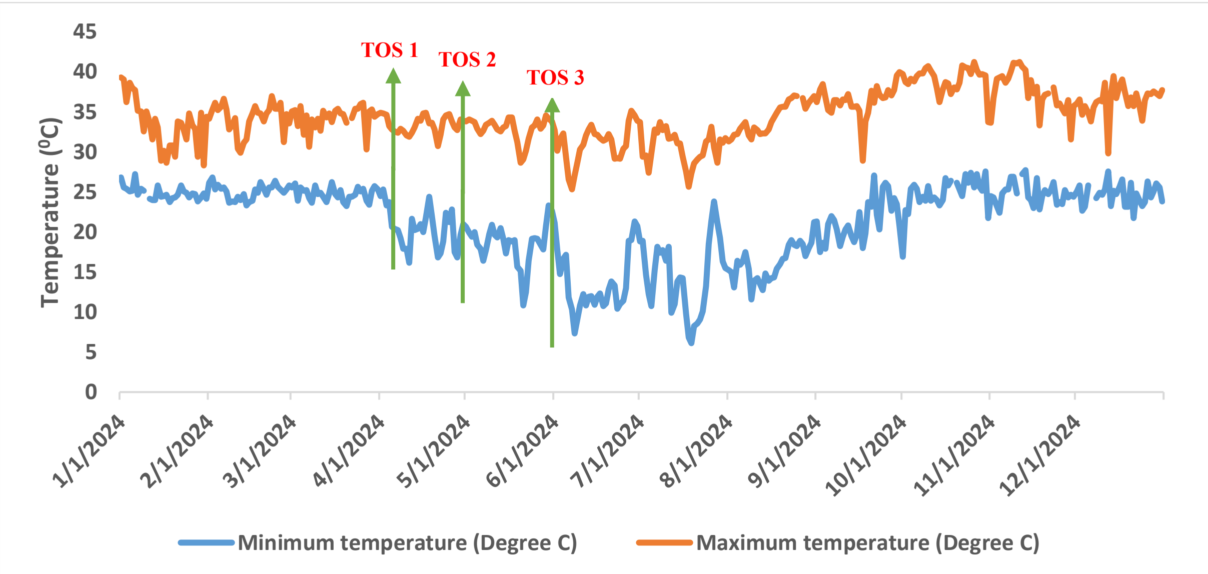

Figure 2: Daily maximum and minimum temperatures recorded at KRS in 2024. Green vertical arrows indicate the sowing times.

Fertiliser recommendations were based on soil analysis results from the trial site (Appendix 3; Table A3.1). Table 2 summarises the timing and application rates of major nutrients to the trial. In contrast to previous seasons, this season an extra top dressing of urea fertilizer was applied to meet the additional nutrient requirements of the late maturing varieties.

Table 2: Nutrient application summary to Industrial Hemp Variety Trial for all sowing times at KRS in 2024.

Product Name	Rate (kg/ha)	Time of application
Di-Ammonium Phosphate (DAP)	300	Prior to sowing
Muriate of Potash (MOP)	150	Prior to sowing
Gypsum	500	Prior to sowing
1st Top dressing Urea	133	25 Days after emergence
2nd Top dressing Urea	133	40 Days after emergence
3rd Top dressing Urea	133	55 Days after emergence

Pre-emergent herbicide was applied soon after planting for each TOS (Table 3). Following the herbicide application, an irrigation of 8 mm was applied to facilitate seed germination.

Several insect pests were identified at the trial site, including *Helicoverpa armigera* (cotton bollworm), *Spodoptera litura* (Cluster caterpillar), *Isoptera spp.* (Termites), *Spodoptera frugiperda* (Fall armyworm), *Aphis craccivora* (Aphids), *Liriomyza trifolii* (American serpentine leafminer), *Nysius vinitor* (Rutherglen bug) and *Nezara viridula* (Green vegetable bug), and recommended chemicals were applied to manage them. A summary of herbicides/pesticides applied to manage weeds and insect pests are presented in Table 3.

Table 3: Herbicides and Insecticides applied on Industrial Hemp Variety Trial in 2024 at KRS.

Applied to	Product	Classification	Active Ingredient	Rate	Date of Application
TOS 1 & 2 & 3	Rifle	Herbicide	440 g/L pendimethalin	1 l/ha	Immediately after sowing
TOS 1	Fipronil	Insecticide	200 g/L Fipronil	80 ml/ha	03/05/2024
TOS 1& 2 & 3	Alpha Scud	Insecticide	300 g/L Alpha-cypermethrin	100 ml/ha	20/06/2024
TOS 2 & 3	Chloropyrifos	Insecticide	500 g/L Chlorpyrifos	200 ml/ha	11/07/2024

At 50 % flowering, two female flower heads were randomly picked from two plants per plot from all varieties and times of sowing and bulked together into one sample per variety/time of sowing. The flower samples were dried in an oven at 40 ^{0}C for three days (72 hours) and then sent to AST for THC analysis.

Grain harvest was carried out when individual plants in a plot contained 70% hard brown grains. Harvesting was done by cutting individual plants at ground level from a subplot 2 m long x 2 central rows within each trial plot. Harvested plants were placed into woven polyester bags and transferred into an oven for drying at 40 ^{0}C for 72 hours.

The harvested whole plants were weighed to determine the total dry matter from the 1 m^2 area (2 m long x 2 central rows of each trial plot), then threshed to extract grain. The extracted grains were cleaned and weighed to determine the grain yield from the harvested area. The estimates of dry matter and grain yield per plot and hectare were then calculated.

A seed counting machine (Contador seed counter) was used to count seeds to determine 1000 grain weight. Subsamples of seeds were packed in 100 ml plastic containers and sent to AST for analysis of bulk density, protein content, and oil content.

The data was analysed using Genstat statistical software. The design was balanced between time of sowing (TOS) and Variety. Genstat output was provided for the analysis of all measurements.

Multi-season comparison

The trial described above was the third season of IHVT at KRS. In 2022 and 2023 very similar trials were conducted, and results published on the AgriFutures Australia website (Kumar, 2023; Nawaz et al., 2024). The results for key parameters (grain yield, 1000-grain weight, oil and protein content) were compared for all fifteen varieties planted across three growing seasons at KRS trial site.

The combined model fitted was a linear mixed model with fixed model Variety and random model Year.TOS/Rep. The purpose of this model was to provide variety recommendations applicable to a sowing time between end March and end May. In each year the yield was square root transformed to give more constant variance as required for the statistical analysis. The 2022 and 2023 designs had the time of sowing in separate blocks and therefore the time of sowing effects were confounded with spatial trend. For 2024 there was genuine replication of two times of sowing (April and May).

Results

General crop performance

The variation in growth habit of varieties and the influence of sowing time on flowering and harvest is shown in Table 4. For all times of sowing, Bama, Han NE, Yuma and Han Cold took longer to mature, followed by Ruby, whereas Ferimon 12, Muka 76, and CRS-1 were early maturing varieties. Averaged across all long season genotypes, TOS 2 and TOS 3 matured more slowly compared to TOS 1. Temperatures started decreasing in the dry season from June to September (Figure 2) which might be the reason for the longer growing period for later sowing times.

Table 4: Phenology data for the industrial hemp varieties sown at three sowing times at Katherine Research Station in 2024.

Variety	Sowing Date	Male Flowering (DAS)	Female Flowering (DAS)	Harvest (DAS)
Bama	4/04/2024	26	35	90
	30/04/2024	24	35	114
	30/05/2024	32	39	111
CRS-1	4/04/2024	19	24	74
	30/04/2024	24	29	63
	30/05/2024	24	29	75
Han Cold	4/04/2024	27	34	90
	30/04/2024	24	35	114
	30/05/2024	32	39	96
Han NE	4/04/2024	25	34	90
	30/04/2024	24	35	114
	30/05/2024	32	39	111
Ruby	4/04/2024	25	31	74
	30/04/2024	24	33	87
	30/05/2024	32	39	102
Yuma	4/04/2024	27	34	90
	30/04/2024	24	36	114
	30/05/2024	31	39	111
Ferimon 12	4/04/2024	25	27	74
	30/04/2024	24	28	77
	30/05/2024	22	29	81
Muka 76	4/04/2024	24	27	78
	30/04/2024	23	28	77
	30/05/2024	32	31	75

DAS = Days after sowing

The volume of water recorded at the trial plots (Table 5) represents total amount received from both irrigation and rainfall, from sowing till harvest. Total water requirement was impacted by sowing date and the time taken by each variety to reach maturity. It's notable that water requirement decreased with delay in sowing time, the reason might be lower temperatures during the dry season (June - August).

Late maturing varieties (Bama, Han NE, Yuma and Han Cold) used more water to complete their growth cycle than shorter season varieties, across all sowing times.

Table 5: Total volume of water received (irrigation and rain) from sowing to harvest during the 2024 Industrial Hemp Variety Trial at Katherine Research Station.

	TOS 1 (mm)	**TOS 2 (mm)**	**TOS 3 (mm)**
Bama	438	457	280
CRS-1	370	307	188
Han Cold	438	457	243
Han NE	438	457	280
Ruby	370	386	255
Yuma	438	457	280
Fermion 12	370	353	203
Muka 76	390	353	188
Mean	**406**	**403**	**239**

Sex distribution of the different varieties is indicated in Figure 3, as proportion of hermaphrodite, male and female plants within the population, adding up to 100 % in total.

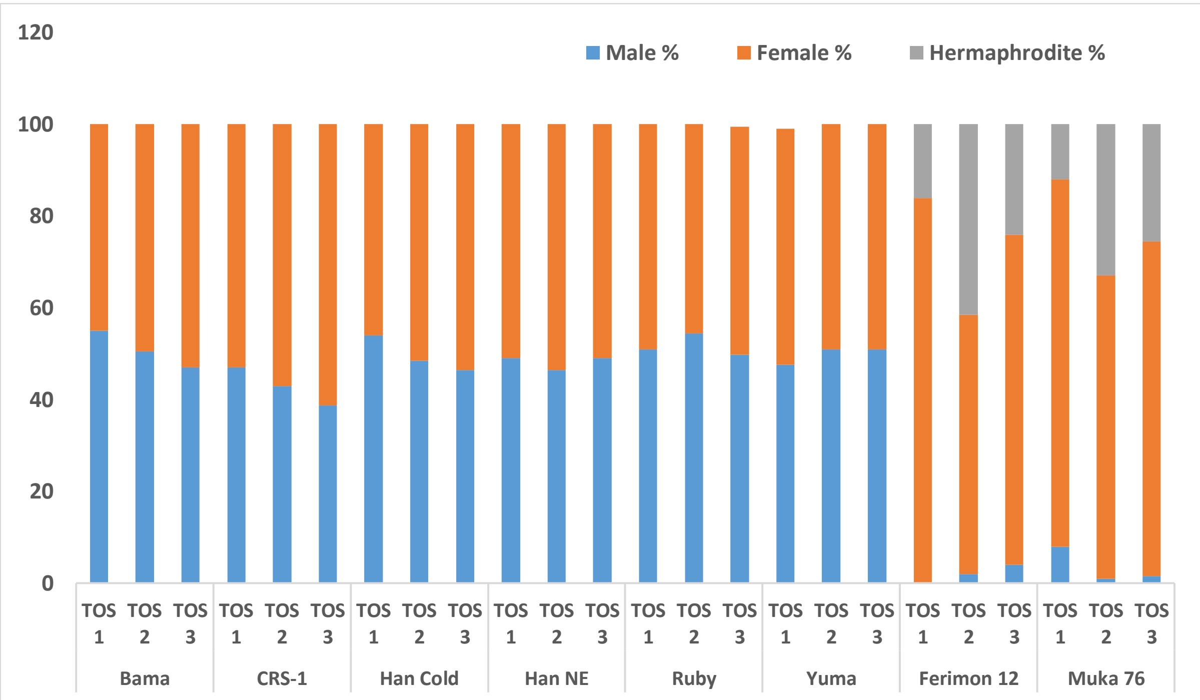

Figure 3: Percentage representation of Male, Female and Hermaphrodite plants (average across replicates) for the 2024 Industrial Hemp Variety Trial at Katherine Research Station.

The dioecious variety CRS-1 consistently produced more female plants than male plants. For the other varieties (Han Cold, Bama, Yuma and Han NE), the ratio of male and female plants was close to 50:50. Ruby had slightly more male plants than female plants.

The monoecious varieties (Ferimon 12 and Muka 76) displayed some hermaphrodite plants in all times of sowings, with the majority of plants being identified as female, and a very low number of male plants.

The inspection timing might have been delayed, resulting in the male flowers on many of the hermaphrodite plants already being spent and thus some of these hermaphrodite plants were mis-identified as Female.

Mean THC level in flower heads averaged across the 3 times of sowing was highest in Ruby (0.196), Han Cold (0.098) and Bama (0.033) (Table 6). However, all readings were well below the 1 % limit required under Northern Territory Industrial Hemp Licenses, indicating that all the varieties were suitable for growing under that jurisdiction's licensing regime. It is important to note that Ruby's THC level in TOS 2 was particularly concerning, as it reached nearly half the allowable level.

Table 6: Tetrahydrocannabinol content (% w/w) in flower heads for eight industrial hemp varieties sown at three times of sowing at Katherine Research Station in 2024.

Variety	TOS 1	TOS 2	TOS 3	Mean
Bama	0.024	0.025	0.051	0.033
CRS-1	0.010	0.015	0.034	0.020
Han Cold	0.022	0.192	0.080	0.098
Han NE	0.021	0.037	0.018	0.025
Ruby	0.034	0.451	0.104	0.196
Yuma	0.018	0.022	0.020	0.020
Fermion 12	0.022	0.025	0.038	0.028
Muka 76	<0.010	0.017	0.022	0.019

Table 7 summarizes the results of statistical analysis of general crop performance parameters. There were significant differences in all growth parameters between varieties. Time of sowing had a significant affect only on plant height, however there were interaction effects for all parameters except dry matter yield.

Table 7: Levels of significance from analysis of variance for general crop performance for three times of sowing (TOS) and eight hemp varieties.

Source of Variation	Plant count at establishment	Plant count at harvest	Plant height at harvest	Total dry matter yield
Variety	***	***	***	***
Time of Sowing	NS	NS	**	NS
Variety x Time of Sowing	*	***	**	NS

*** <0.001, ** <0.01, * <0.05 and NS is not significant

There were significant differences in plant count at establishment among varieties (Figure 4). All varieties (except Ruby during the May planting time) failed to achieve the target density of 150 plants/m^2 in all times of sowing (Figure 4). TOS 3 had the highest plant establishment (96.03 plants/m^2) averaged across all the varieties, while TOS 1 and TOS 2 averaged 58.81 and 58.12 plants/m^2 respectively. The low plant count for all sowing times was likely due to high soil temperatures (above 35 ^{o}C) during planting time (Figure 2) and low viability in seeds leading to poor germination rate (see Appendix 2). Soil temperature significantly affects the emergence and early growth of hemp seeds, therefore, temperature was recorded on the surface and at seed depth for initial 21 days of crop establishment for all sowing times, as shown in Figure 5, 6 and 7.

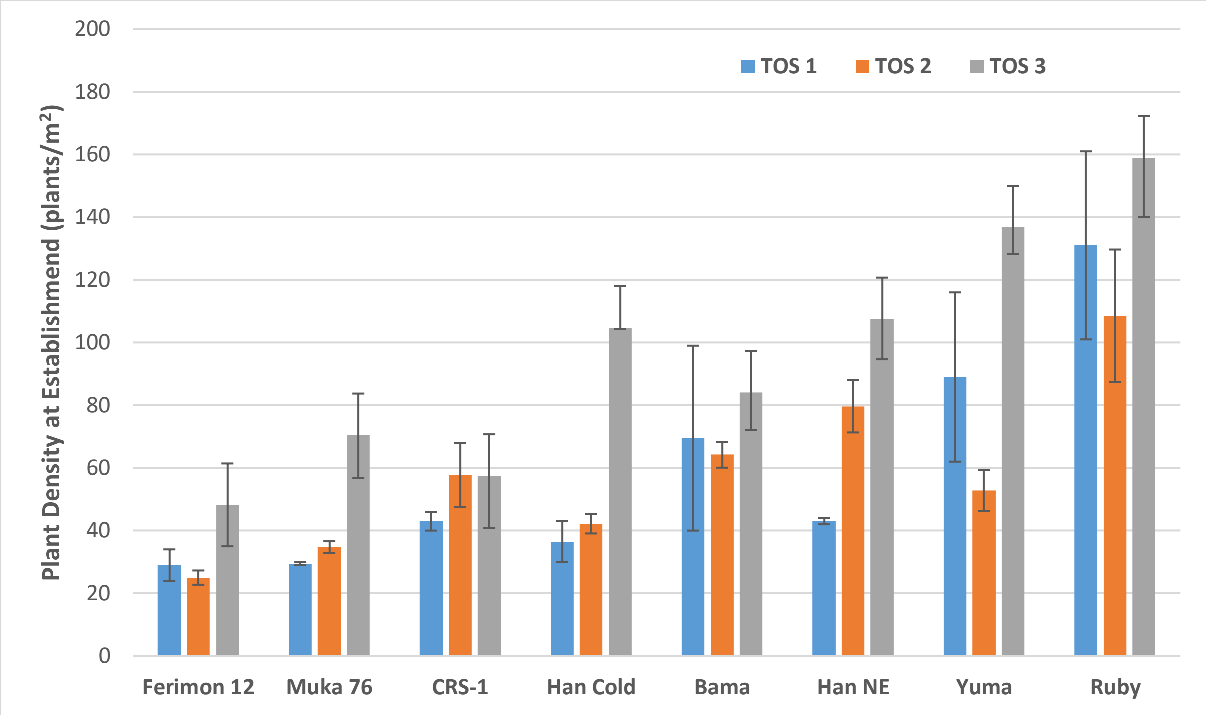

Figure 4: Average plant density at establishment of eight hemp varieties sown at three sowing times at Katherine Research Station in 2024. Error bars show the standard error (SE) across four replicates at $p \leq 0.05$.

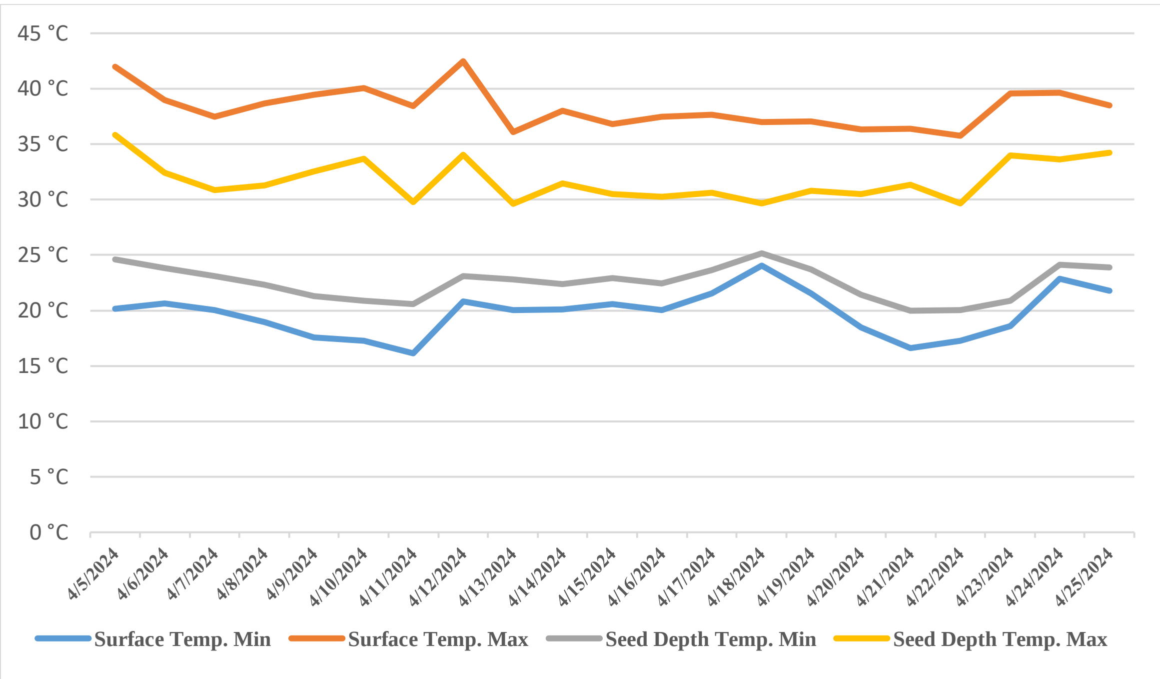

Figure 5: Daily Maximum and Minimum temperatures (surface and seed depth) during the initial 21 days after sowing of TOS 1.

Plant density was very low for TOS 1 across all varieties averaging at 61 plants/m^2, with Ruby the highest variety and Ferimon-12 the lowest. Maximum surface temperature in the 21 days after sowing was below 40 ^{0}C whereas average maximum seed depth temperature was above 30 ^{0}C (Figure 5).

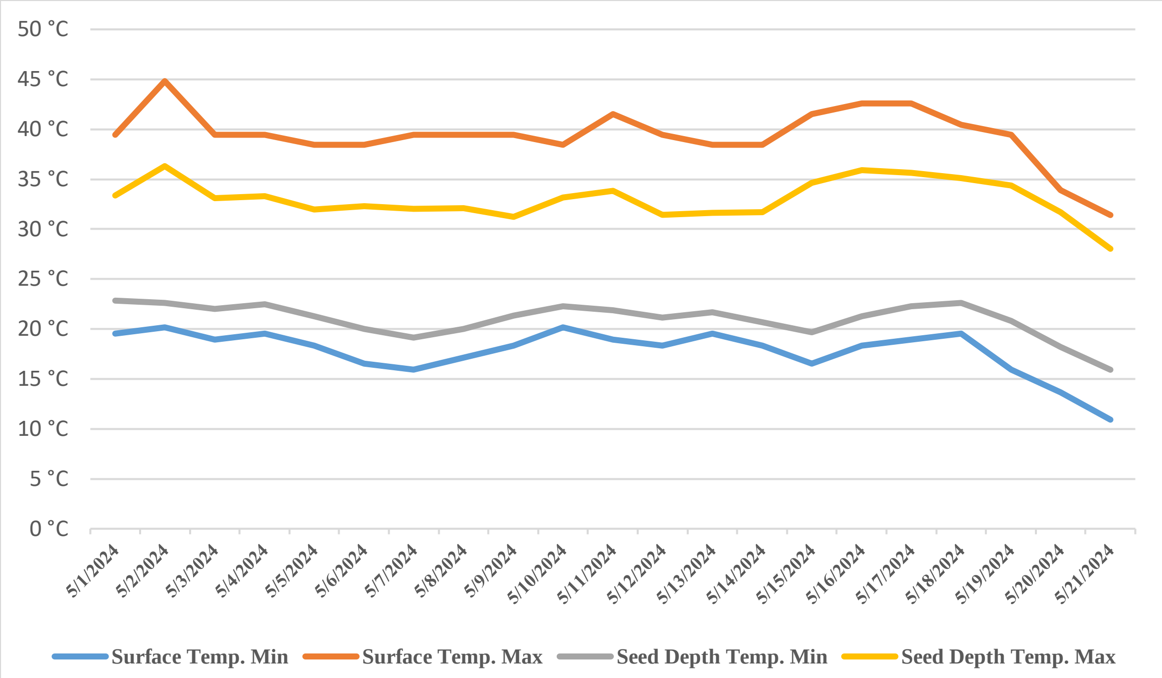

Figure 6: Daily Maximum and Minimum temperatures (surface and seed depth) during the initial 21 days after sowing of TOS 2.

Seedling establishment was also low for TOS 2. Highest plant count was recorded for Ruby (108.5 plants/m^2) whereas lowest was observed in Ferimon-12 (25 plants/m^2). Soil surface maximum temperature after sowing was at around 40 ^{0}C whereas seed depth highest temperature was above 30 ^{0}C (Figure 6).

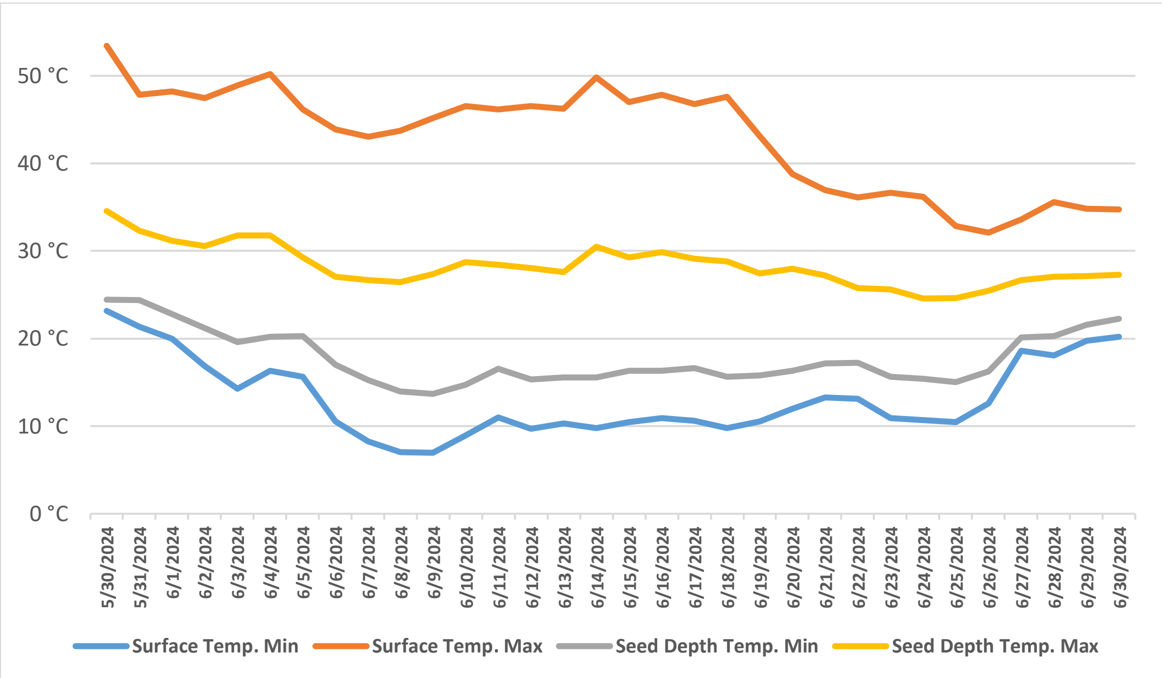

Figure 7: Daily Maximum and Minimum temperatures (surface and seed depth) during the initial 21 days after sowing of TOS 3.

Crop establishment was better in TOS 3 as compared to April sowing (TOS 1 & 2). Ruby achieved 159 plants/m^2 followed by Yuma (136.8 plants/m^2), and Ferimon-12 recorded the lowest population at 48.2

plants/m^2. Surface soil temperature was very high (above 45 ^{0}C) for the initial 18 days after sowing and then dropped down below 35 ^{0}C after 25th May. Soil temperature at seed depth remained below 30 ^{0}C for the complete crop establishment phase (Figure 7). Lower soil temperatures at seed depth enabled better crop establishment for all varieties at TOS 3.

Plant counts taken at harvest indicated similar trends for varieties and times of sowing but interaction between variety and time of sowing was significant (Figure 8). A decrease in average number of plants within all varieties for all sowing times was observed at harvest. The difference in plant density between establishment and harvest is likely to be because of external factors such as weather conditions, pest and diseases damage.

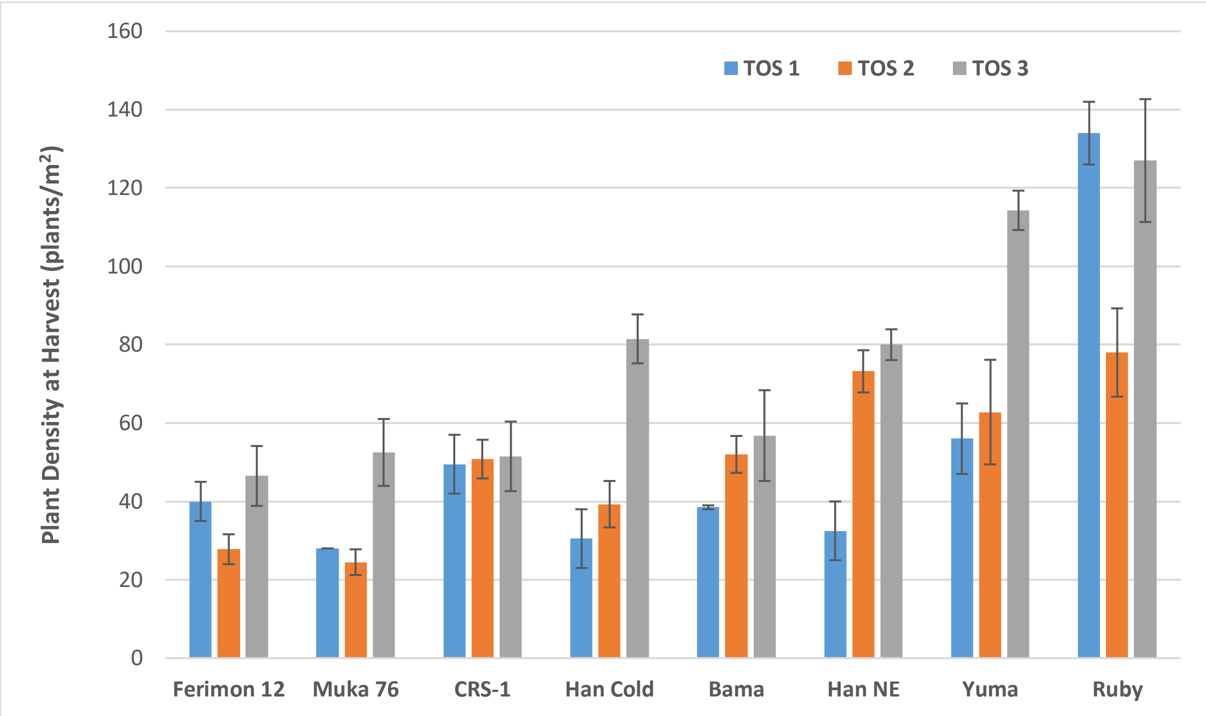

Figure 8: Average plant density at harvest of eight hemp varieties sown at three sowing times at Katherine Research Station in 2024. Error bars show the standard error (SE) across all replicates at $p \leq 0.05$.

Han Cold (208 cm) had the tallest plant height at harvest in TOS 1 followed by Bama (188.6 cm), Yuma (176.5 cm) and Han NE (171.4 cm), whereas Ferimon-12 had shortest plant height of 31.3 cm in TOS 2 (Figure 9). Generally, plant height was greatest in TOS 1 averaging 138.2 cm followed by TOS 2 (85.4 cm) and TOS 3 (81.4 cm). All the European and Canadian varieties remained shorter whereas Chinese varieties were taller.

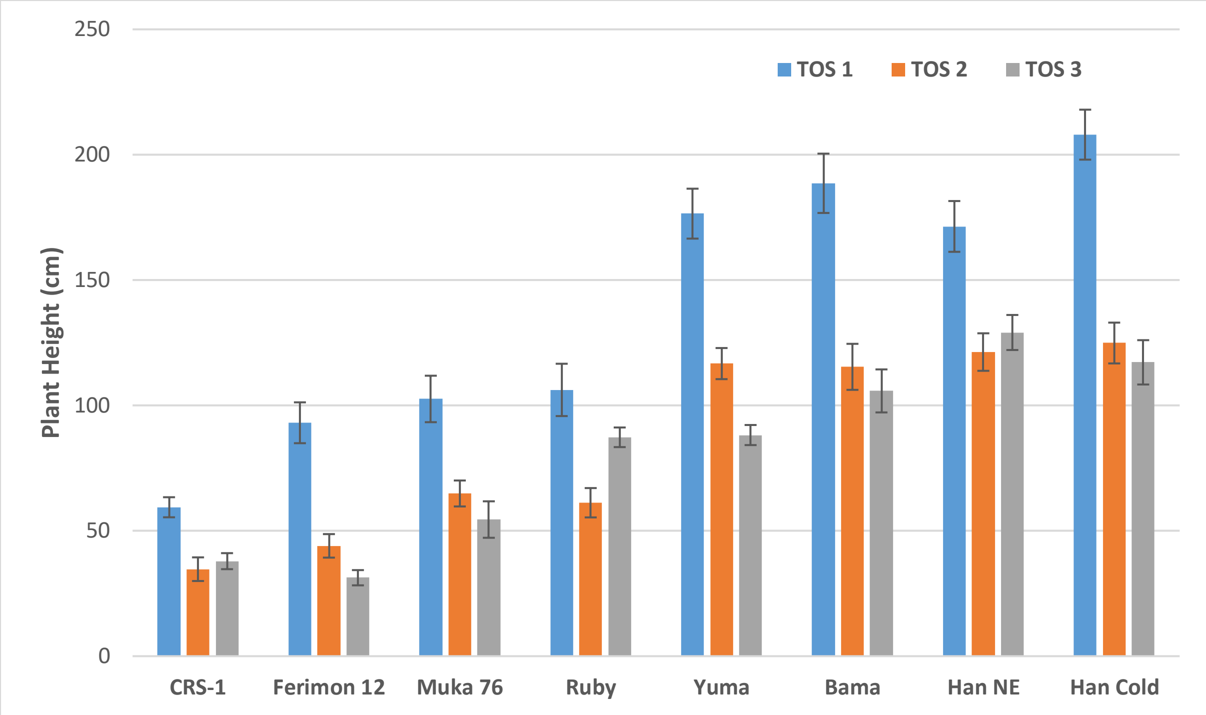

Figure 9: Average plant height of eight hemp varieties sown at three sowing times at Katherine Research Station in 2024. Error bars show the standard error (SE) across all replicates at $p \leq 0.05$.

Varieties exhibited significant differences in dry matter yield (Figure 10). Averaged across all sowing times, Yuma produced the highest dry matter yield of 4.69 t/ha followed by Han Cold (4.25 t/ha) and Han NE (3.95 t/ha) whereas CRS-1 produced the lowest dry matter yield of 0.961 t/ha. The Chinese varieties (Bama, Han NE, Han Cold and Yuma) generally produced higher dry matter than the other varieties.

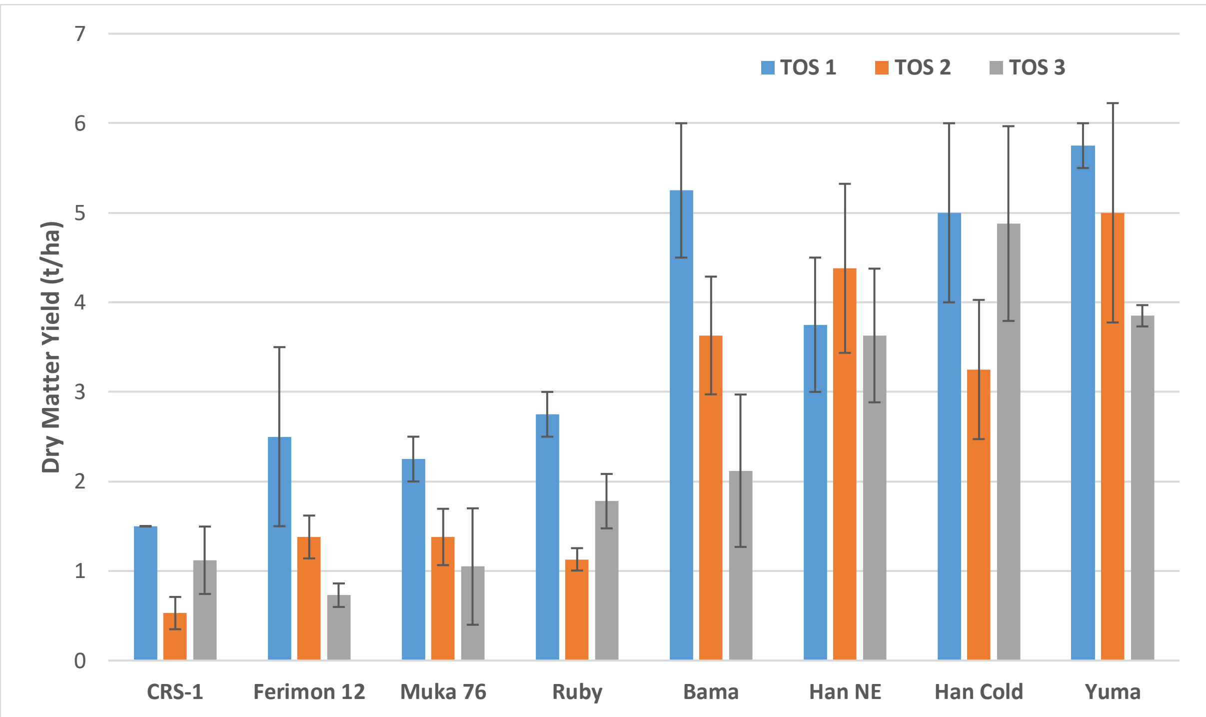

Figure 10: Average dry matter yield of eight hemp varieties sown at three sowing times at Katherine Research Station in 2024. Error bars show the standard error (SE) across all replicates at $p \leq 0.05$.

Grain yield and quality parameters

Statistical analysis showed a strong variety effect and a significant variety by TOS interaction on grain yield and quality, except 1000-grain weight (Table 8).

Table 8: Levels of significance from analysis of variance for grain quality parameters for three times of sowing (TOS) and eight hemp varieties.

Source of Variation	Grain yield	1000 grain weight	Grain bulk density	Grain Oil content	Grain Protein content
Variety	***	***	***	***	***
Time of Sowing	NS	NS	*	**	*
Variety x Time of Sowing	*	NS	*	***	***

*** <0.001, ** <0.01, * <0.05, <0.1 and NS is not significant

Han NE produced the highest grain yield of 1.21 t/ha, followed by Bama (1.05 t/ha), and Han Cold (1.02 t/ha) averaged across all times of sowing (Figure 11). Muka 76 performed poorly in terms of grain yield (0.49 t/ha) across all sowing times.

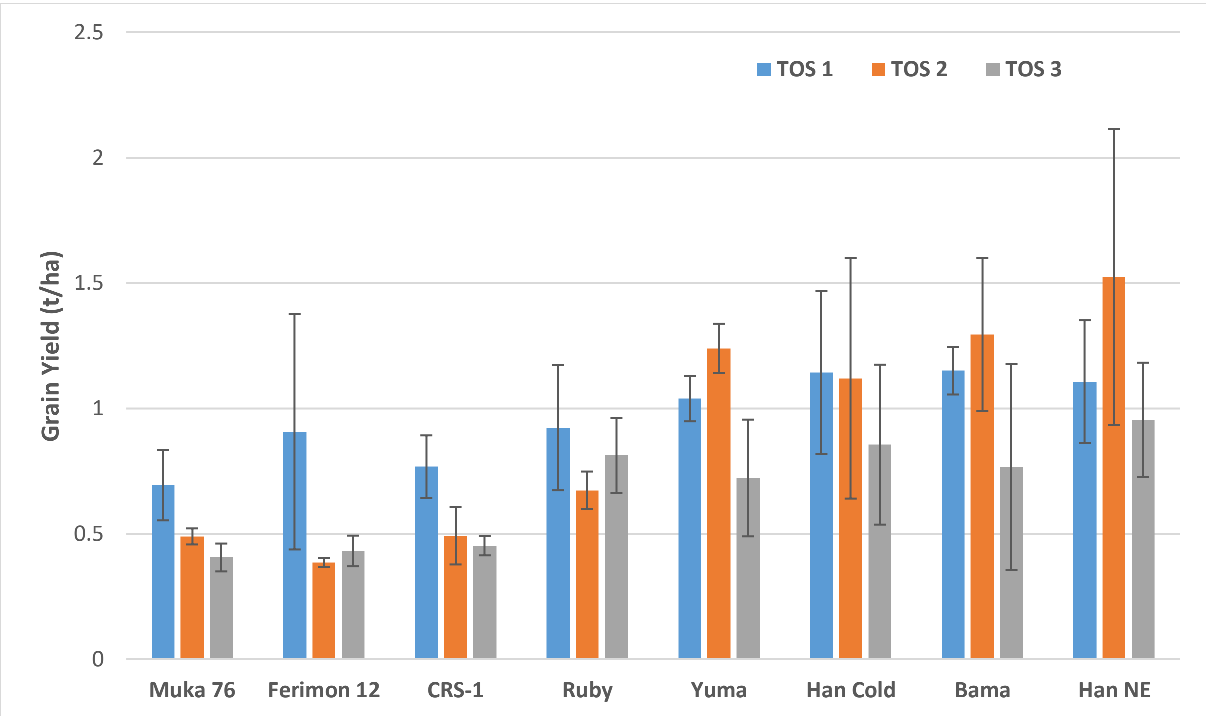

Figure 11: Average grain yield of eight hemp varieties sown at three sowing times at Katherine Research Station in 2024. Error bars show the standard error (SE) across all replicates at $p \leq 0.05$.

The time of sowing and time of sowing by variety interaction was not significant for 1000 grain weight (Table 8), but variety had a significant effect. The Chinese varieties produced consistently higher grain weight than all other varieties, while Ruby produced heavier grains than the remaining varieties.

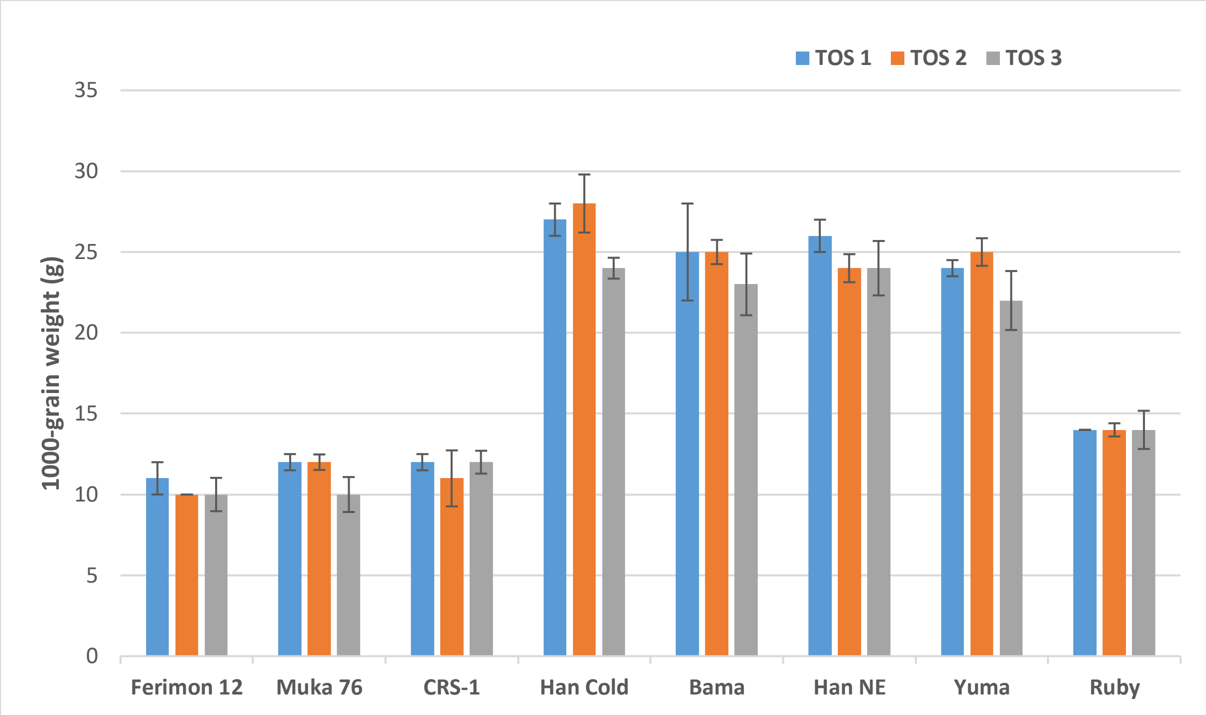

Figure 12: Average 1000-grain weight of eight hemp varieties sown at three sowing times at Katherine Research Station in 2024. Error bars show the standard error (SE) across all replicates at $p \leq 0.05$.

Across all varieties, significant differences for grain bulk density were observed. However, for time of sowing and interaction between variety and time of sowing low significant differences were recorded (Table 8). Ruby and Han NE had the highest grain bulk density content across all three times of sowing, averaging 49.52 and 49.44 kg/hL respectively, while the lowest grain bulk density was recorded in Muka 76, averaging 45.18 kg/hL across all three times of sowing (Figure 13).

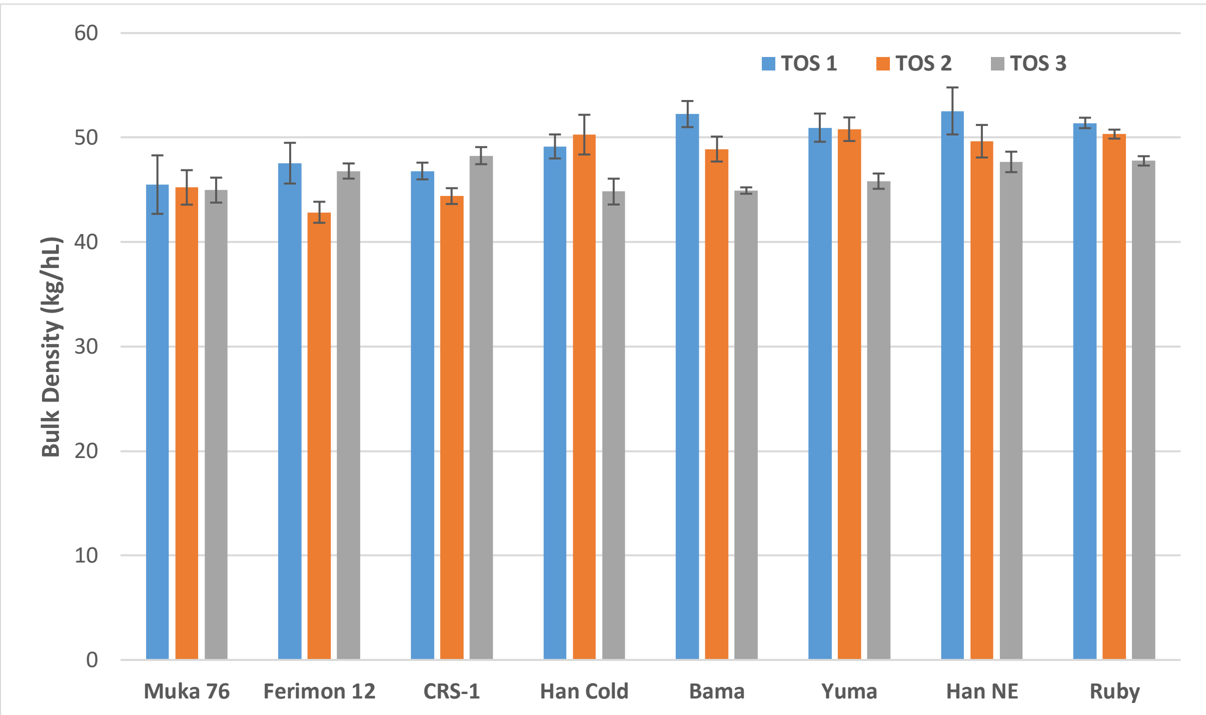

Figure 13: Average bulk density of grain of eight hemp varieties sown at three sowing times at Katherine Research Station in 2024. Error bars show the standard error (SE) across all replicates at $p \leq 0.05$.

Data obtained for total grain oil content indicated that there were highly significant differences among varieties, times of sowing and their interaction (Table 8). Total oil content ranged from 22.4% in Yuma (TOS 3) to 31.95% in Ruby (TOS 1), and across planting dates, TOS 1 had the highest oil content whereas TOS 2 and TOS 3 were statistical at par and ranked lower as shown in Figure 14.

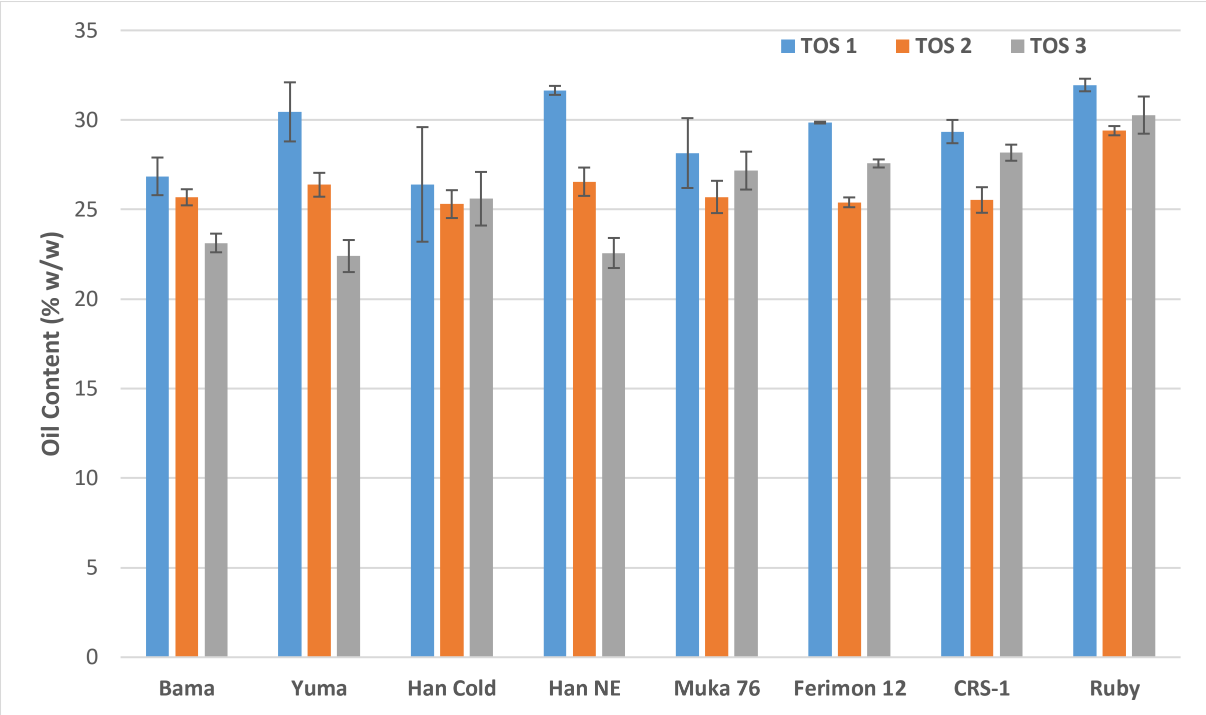

Figure 14: Average oil content of grain of eight hemp varieties sown at three sowing times at Katherine Research Station in 2024. Error bars show the standard error (SE) across all replicates at $p \leq 0.05$.

Average protein content of the grain for all varieties was between 20% and 28%, with significant differences among varieties, times of sowing and their interaction (Table 8). The highest average grain protein was produced by Ruby (28.46%), while Bama produced the lowest protein content of 22.31% (Figure 15).

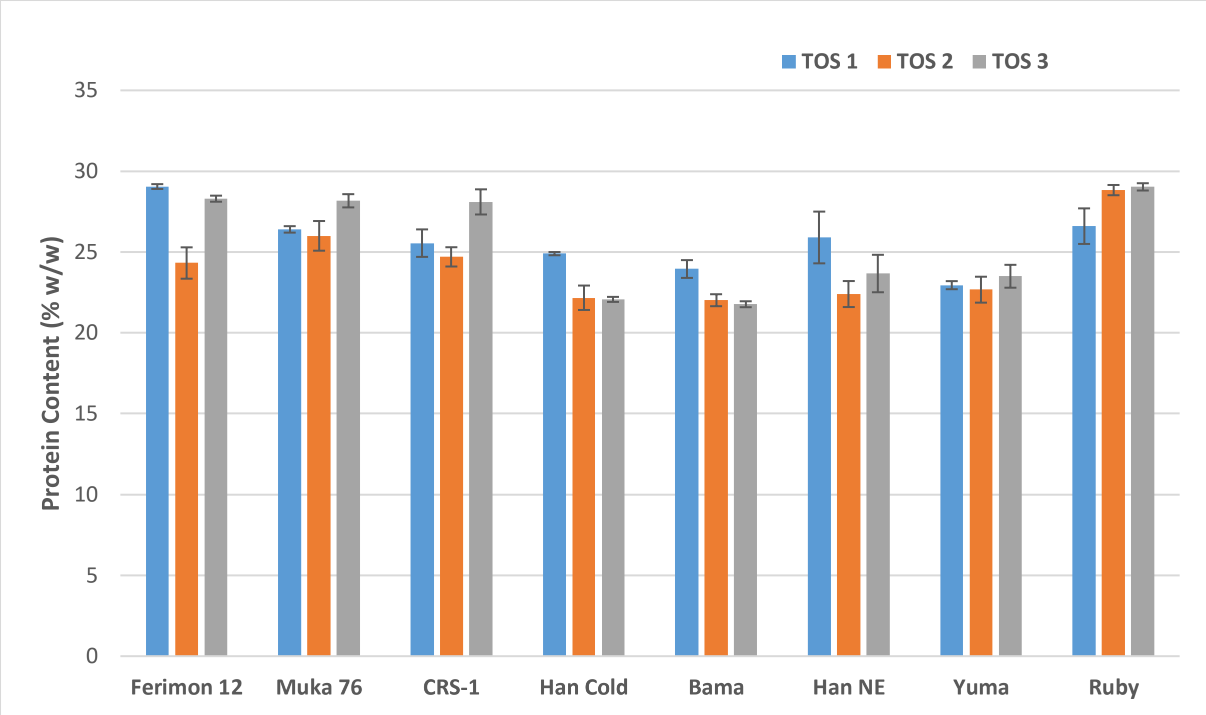

Figure 15: Average protein content of grain of eight hemp varieties sown at three sowing times at Katherine Research Station in 2024. Error bars show the standard error (SE) across all replicates at $p \leq 0.05$**.**

Multi-season comparison

Average grain yield from Han Cold (1.31 t/ha) and Yuma (1.29 t/ha) was significantly higher than other varieties across all three seasons and three sowing times, whereas Henola (0.251 t/ha) performed poorly for grain yield (Figure 16). Han Cold, Yuma, King Gee, Bama and Han NE produced average grain yield above 1 t/ha whereas the rest of the varieties were below 1 t/ha yield. Chinese and Australian varieties performed better while all temperate originating varieties failed to produce commercially viable grain yields.

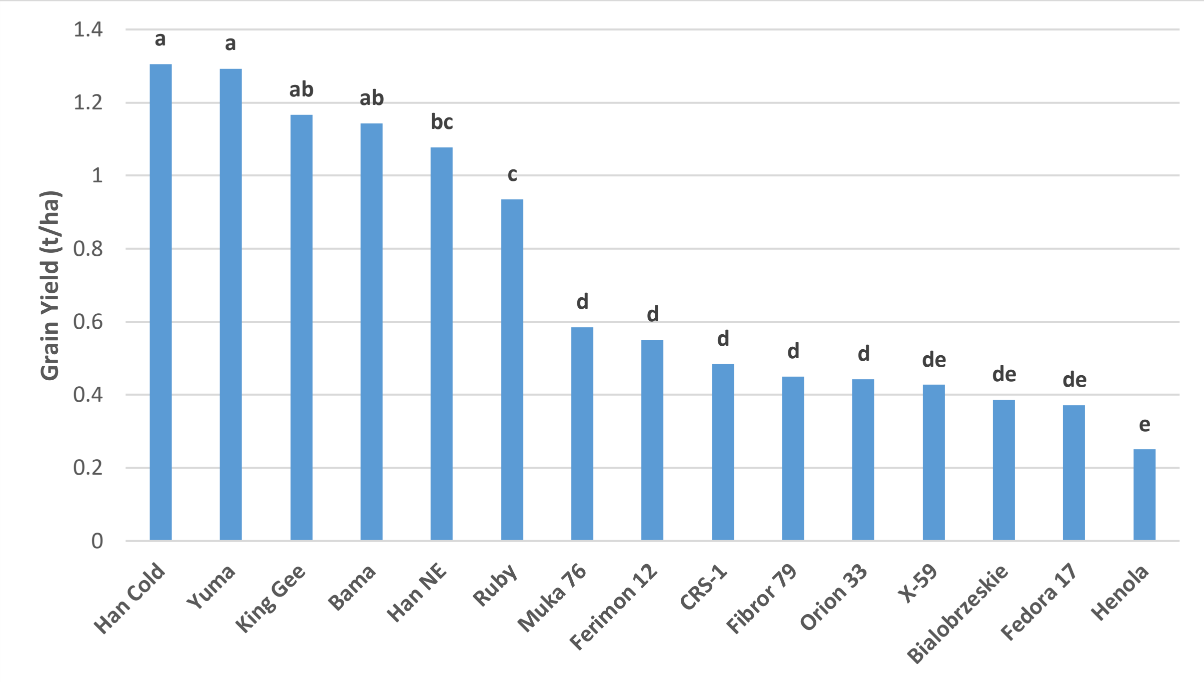

Figure 16: Average grain yield across three seasons and three sowing times for fifteen industrial hemp varieties sown at Katherine Research Station. Means not sharing a letter differ significantly at $p \leq 0.05$.

Varieties differed significantly in 1000 grain weight, with Yuma (23.81 g) and Bama (23.21 g) having heavier seeds, while Henola produced the lightest seeds at 6.73 g averaged across three seasons and three sowing times (Figure 17).

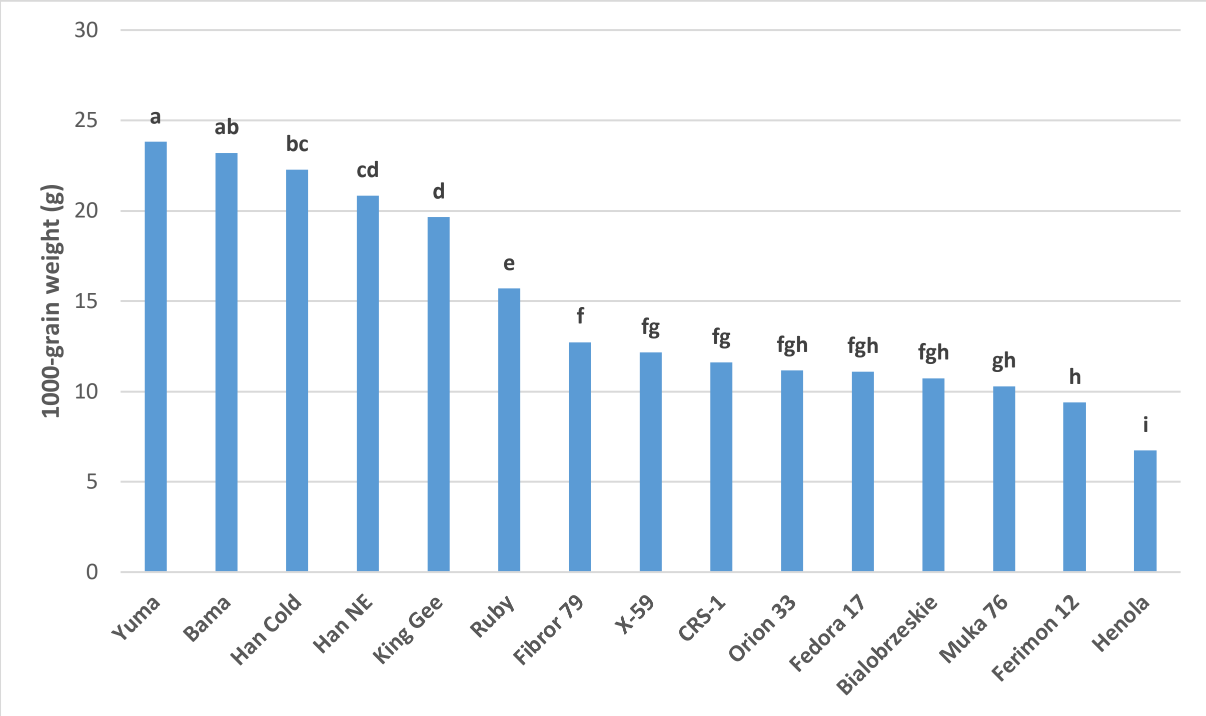

Figure 17: Average 1000-grain weight across three seasons and three sowing times for fifteen industrial hemp varieties sown at Katherine Research Station. Means not sharing a letter differ significantly at $p \leq 0.05$.

Ruby (29.93 %) and King Gee (28.68 %) produced the highest oil content while Henola (14.66 %) produced lowest oil content across all the three seasons and three sowing times (Figure 18).

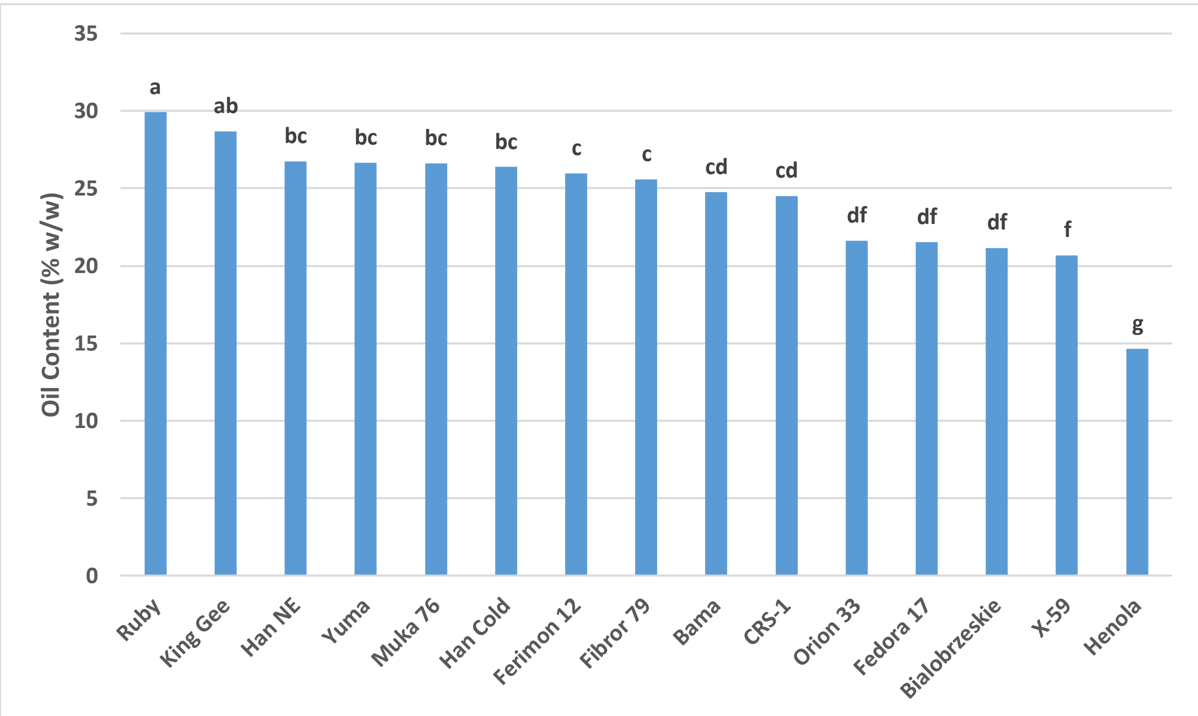

Figure 18: Average oil content across three seasons and three sowing times for fifteen industrial hemp varieties sown at Katherine Research Station. Means not sharing a letter differ significantly at $p \leq 0.05$.

Dry matter yield was highest in King Gee (2.577 t/ha), Yuma (2.476 t/ha) and Han Cold (2.454 t/ha), while the lowest was recorded in X-59 (0.975 t/ha), averaged across the 3 years and three sowing times (Figure 19).

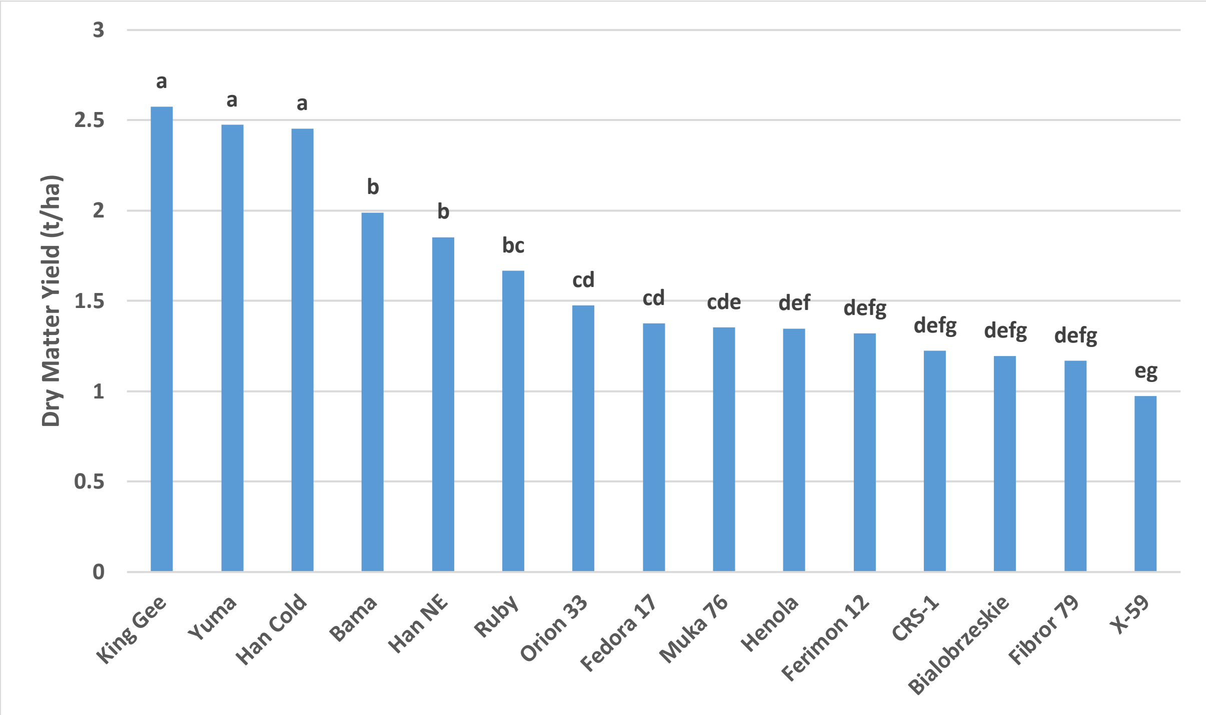

Figure 19: Average protein content of grain across three seasons and three sowing times for fifteen industrial hemp varieties sown at Katherine Research Station. Means not sharing a letter differ significantly at $p \leq 0.05$.

Implications

By providing region-specific agronomic information, potential NT growers of industrial hemp can make informed decisions, fostering confidence in hemp production.

This research has highlighted several production challenges, such as seed quality, soil temperature at sowing, integrated pest and disease management and irrigation. High quality seed are crucial for successful hemp cultivation. Safe seed handling and storage measures should be taken to ensure high germination seed rates and good seedling vigour. There should be regular seed viability testing in order to assess the germination potential, which is critical for healthy crop establishment.

Soil temperature play a significant role in the germination and early growth of hemp plants. Sowing at the right soil temperature ensures optimal seed germination and seedling development. For NT growers, sowing too early can lead to poor germination rates and affecting overall crop yield and quality.

Agronomic information is important in establishing an integrated pest management plan for this newly emerging crop, specific to NT growing conditions. This includes regular monitoring of pest and disease pressures, implementing cultural practices/chemical interventions to reduce pest populations. Effective irrigation management is also critical for hemp cultivation, particularly when sowing in dry season within NT. Understanding the water requirements of hemp at different growth stages helps in optimizing irrigation schedules and techniques. Regular soil moisture monitoring and adjusting irrigation based on weather conditions and crop needs can further enhance water use efficiency.

The fifteen varieties tested during the life of the project have shown consistent performance for most attributes. The trial results validated varietal performance across seasons and will give more confidence to growers in making informed decisions.

Continuity of research funding for industrial hemp research by Agrifutures Australia has been guaranteed by the establishment of the five-year Australian Industrial Hemp Program of Research, focusing on four key areas: hemp seeds and varieties, hemp primary production, hemp products and hemp sustainability.

Recommendations

It is recommended that:

- NT growers consider planting Han Cold, Yuma and/or King Gee for dual-purpose (biomass and grain) production in the Katherine region or similar growing environments.

- The IHVT revealed the impact of low-quality seed on germination and crop establishment. Implementing stringent quality control measures for seed procurement and handling will enhance seed viability and, consequently, crop establishment.

- Further research should address other critical agronomic issues such as plant nutrition, water management, and the effect of high temperature on crop establishment and yield.

- Establishing a centralized platform for data sharing and coordination among stakeholders would ensure transparent dissemination of findings and best practices across growing regions.

Appendices

Appendix 1: Soil profile descriptions and physical properties in KRS

KRS has Tippera soil, which belongs to the loamy subgroup of the Red Earths, they have a porous earthy profile and are well drained. These soils commonly occur on sediments of the Jinduckin formation, a unit of siltstone with bands of dolomite and sandstone, but sometimes are associated with the Tindall limestones (Aldrick & Robinson, 1972).

Soil Family: Tippera

Australian Soil Classification: Haplic Mesotrophic Red Kandosol

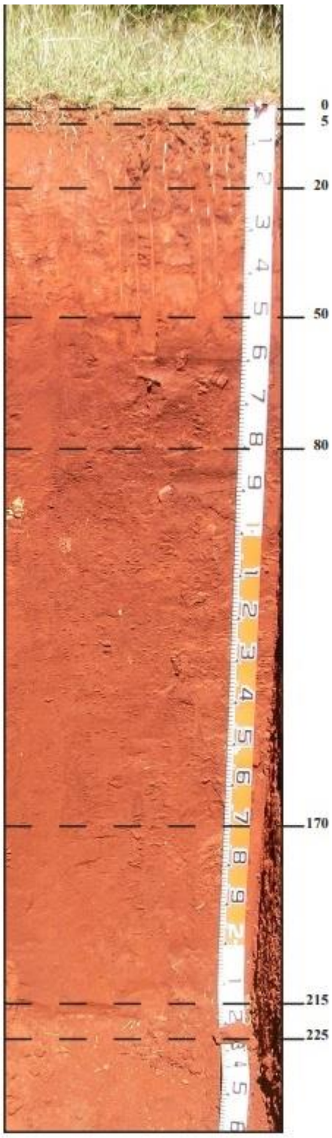

Figure A1.1: Soil profile of Katherine Research Station (Edmeades, B. F. (2011), see Table A1.1 for further interpretation.

Table A1.1: Physical properties of soil profile of Katherine Research Station (Observed in 2011).

Depth (cm)	Horizon	Description
Surface	-	Hard setting; non-gravelly.
0-5	**A11**	Dark reddish brown; sandy loam texture; massive, earthy; dry, firm and non-sticky consistence; non-gravelly; $pH_{1:5}$ 6.7; $EC_{1:5}$ 0.0
5-20	**A12**	Dark reddish brown; sandy loam texture; massive, earthy; dry, firm and non-sticky consistence; non-gravelly; $pH_{1:5}$ 6.7; $EC_{1:5}$ 0.0
20-30	**A3**	Dusky red; sandy loam texture; massive, earthy; dry, very firm and non-sticky consistence; non-gravelly; $pH_{1:5}$ 6.9; $EC_{1:5}$ 0.0
30-45	**B1**	Dusky red; clay loam texture; massive, earthy; dry, strong and slightly sticky consistence; non-gravelly; $pH_{1:5}$ 7.1; $EC_{1:5}$ 0.0
45-90	**B21**	Dusky red; light clay texture; massive, earthy; moderately moist and slightly sticky consistence; non-gravelly; $pH_{1:5}$ 7.2; $EC_{1:5}$ 0.0
90-220	**B22**	Dark red; light medium clay texture; massive, earthy; moist and slightly sticky consistence; non-gravelly; $pH_{1:5}$ 7.2; $EC_{1:5}$ 0.0

Source: Properties of selected soils in the Douglas and Katherine Regions, Technical report 2011, Natural Resources Division, Department of Natural Resources, Environment, The Art and Support.

Appendix 2: Sowing rate calculations based on germination percentage of seed

Sowing rate for each variety was calculated using the germination percentage obtained from each batch of seed.

Table A2.1: Sowing rate calculations for planting trial at KRS 2024.

Variety	Seed Weight Received (kg)	Target Plant Density/m2	Plot area (1.5*5 m)	target number of plants per plot	Germination %	Number of seeds required after adding loss of germination	10 % added for loss in establishment	1000 seed weight (g)	g of seeds per plot
Bama	3.45	150	7.5	1125	58	1940	2155	33	71
Han Cold	3.45	150	7.5	1125	50	2250	2500	35	88
Han NE	3.05	150	7.5	1125	55	2045	2273	33	75
Ruby	2.70	150	7.5	1125	50	2250	2500	19	48
Yuma	2.95	150	7.5	1125	50	2250	2500	32	80
CRS-1	1.50	150	7.5	1125	50	2250	2500	18	45
Ferimon 12	2.50	150	7.5	1125	50	2250	2500	17	43
Muka 76	1.50	150	7.5	1125	50	2250	2500	16	40

Appendix 3: Soil chemical properties of KRS trial site

Soil samples were taken from 3 locations at four depths (0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm) within the trial site prior to sowing the trial and samples were sent to CSBP lab in Western Australia for comprehensive analysis.

Table A3.1: Soil chemical properties at the Katherine Research Station trial site prior to amelioration.

Site	Depth	Gravel	Texture	Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulfur	Organic Carbon	Conductivity	pH Level (CaCl2)	pH Level (H2O)	DTPA Copper	DTPA Iron	DTPA Manganese	DTPA Zinc	Exc. Aluminium	Exc. Calcium	Exc. Magnesium	Exc. Potassium	Exc. Sodium	Boron Hot CaCl2
	cm	%		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%	dS/m			mg/kg	mg/kg	mg/kg	mg/kg	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	mg/kg
Location 1	0-30	5	2.5	2	1	8	183	1.2	0.36	0.025	6.5	7.8	1.89	3.40	23.80	0.28	0.050	3.74	1.62	0.35	0.03	0.21
Location 1	30-60	5-10	2.5	1	1	< 2	68	9.2	0.14	0.031	6.5	7.3	0.94	1.70	4.99	0.16	0.070	4.19	1.86	0.12	0.03	0.31
Location 1	60-90	5-10	2.5	< 1	< 1	2	58	27.2	0.09	0.038	6.3	7.2	0.54	1.40	1.64	0.22	0.140	3.97	1.80	0.11	0.02	0.34
Location 1	90-120	5-10	2.5	7	1	< 2	65	28.2	0.06	0.042	6.2	6.9	0.51	1.60	0.84	0.19	0.190	3.84	1.95	0.11	0.02	0.35
Location 2	0-30	5-10	2.5	1	3	9	108	1.8	0.34	0.034	7.0	8.1	1.89	1.80	15.46	0.49	0.100	4.67	1.93	0.23	0.03	0.24
Location 2	30-60	5-10	2.5	< 1	3	4	75	4.7	0.15	0.040	7.2	8.2	1.15	1.60	7.14	0.21	0.150	4.45	2.11	0.15	0.03	0.23
Location 2	60-90	5-10	2.5	< 1	2	< 2	77	12.7	0.08	0.035	6.8	7.6	0.60	1.30	2.34	0.15	0.190	3.91	1.98	0.16	< 0.01	0.21
Location 2	90-120	5-10	2.5	< 1	2	2	48	9.2	0.09	0.029	6.9	7.9	0.54	4.80	1.45	0.03	0.160	3.58	1.89	0.10	< 0.01	0.21
Location 3	0-30	5-10	2.0	1	6	20	165	1.8	0.39	0.051	7.3	8.4	1.52	1.90	15.67	0.73	0.130	5.13	1.75	0.33	0.02	0.29
Location 3	30-60	5-10	2.5	< 1	4	3	166	3.9	0.09	0.037	7.1	8.2	0.93	1.40	5.32	0.17	0.140	4.22	1.90	0.32	0.03	0.32
Location 3	60-90	5-10	2.5	< 1	1	< 2	103	9.4	0.06	0.037	7.0	7.9	0.55	1.60	2.26	0.38	0.190	4.19	2.12	0.25	0.01	0.26
Location 3	90-120	5-10	2.5	< 1	1	3	90	5.6	< 0.05	0.029	7.0	8.1	0.44	1.40	0.78	0.17	0.120	3.87	2.15	0.18	0.01	0.23

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