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# Yield Potential and Trait Correlations in Early-Maturing, Southeastern-Bred U.S. Winter Canola

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## Abstract

Canola is an important oil crop for the United States. Winter canola is limited to areas with mild winters of the Mid-South, compared to summer canola found in Northern Plains. When grown in this region, winter canola can precede row crops such as corn, cotton or soybeans but must mature early enough to not interfere with their full season. The objective of our research was to evaluate a group of 22 open-pollinated canola genotypes, including lines bred in the Southeast for earliness in time to flowering with these compared to released varieties that are later in maturity as checks. The trials were conducted in Nashville across two fall to spring seasons with planting in October and harvests in May. Several phenological traits for earliness to flower or mature were evaluated by field observation in season one and by UAV drone in season two. NIRs analysis was used for oil and protein. AAMU lines were at least a week earlier in flowering and maturing than checks; but as a result, had a corresponding yield penalty. The first season's yields were superior to the second season's yield. Among the checks, Virginia and Sumner were similar in yield potential and somewhat early compared to the other released varieties with high yields, Riley and Wichita. Some AAMU lines with up to 2348 and 1810 Kg·ha$^{-1}$ yields surpassed Virginia but not Riley, Sumner or Wichita. Overall, the protein content was negatively correlated with the oil content and the yield. AAMU lines were found to be harvestable by mid-May. This timing could allow earlier planting of other row crops. Continued investigation into the early maturity, yield potential and cold hardiness of these winter canola lines for the Mid-South region is suggested.

**Keywords**

*Brassica napus*, Cover Crop, Plant Phenology, Southern Agriculture, Yield Potential

## 1. Introduction

Canola (*Brassica napus* subsp. napus) is an important oil crop for countries with cool growing seasons especially in East Asia, Europe, and North America [1]. It was originally bred from three species, *Brassica napus*, *B. rapa* and *B. juncea*, with the first of these being the most important. In North America and Europe, canola can be divided into 1) spring/summer varieties grown in Canada and northern United States, with primary production being in North Dakota, Minnesota, and the Prairie Provinces [2]; 2) winter varieties grown primarily in states from Virginia to Texas. Other temperate climates of the European Union such as in France, Germany, Poland, and the United Kingdom also have production of winter canola [3]. Meanwhile, in Australia, canola is grown in areas with winter rains [4]; while in China, it is widely grown in fall to spring season along coasts and valleys [5]. A similar, mid-latitude growing area for winter canola is found in the Southeastern parts of the U.S including Gulf States of Alabama, Louisiana and Mississippi plus East Coast states of Georgia, North and South Carolina, and Virginia [6] [7]. Inland states of Arkansas, Kansas, Kentucky, Missouri, Oklahoma, and Tennessee can also produce canola [1] [8].

Previous studies indicate significant potential for winter canola in North America [9] with an average yield of 2500 Kg·ha$^{-1}$ and maximum attainable yield projected to be 5000 to 7000 Kg·ha$^{-1}$. Given fluctuating temperatures, especially due to climate instability and winter cold fronts in the interior states of the mid-South, two primary concerns are the date of planting in the fall and date of harvest in the spring. Early fall establishment of canola root system and growing tips are key to survival across the winter months [10]. Winter canola is often double-cropped after a summer crop making planting in September impractical [11]. Thus, winter canola is planted in September or early October in the Mid-South and October or early November in the Southeast. Fertility is also key to good harvests, with nitrogen applied at rates of 100 to 200 Kg·ha$^{-1}$ recommended for Tennessee [12].

Inevitably, for early or late fall plantings, some leaf dieback and seedling death occur with winter canola and the impacts will depend on the severity of freezes that occur sporadically across the cooler months [1] [8] [13]. Extremely cold conditions in winter and/or severe freezes at flowering can lead to low yields in the Mid-South [12]. However, cold weather does not always reduce yields as canola can fill in for neighboring plants, and therefore some plant thinning by freeze damage is tolerated in crop fields [8]. Drought at planting and delayed germina-

tion may obviate any benefits from early fall planting [1], and September to October tend to be the driest months in Tennessee. Therefore, the November planting of canola is not out of the question. One advantage of this is that the canola's growing point is more dormant during the cold weather of winter.

Stem elongation, known as bolting, is a serious problem when canola is planted too early, especially for vigorously developing varieties [1]. In this case, the growing point is overexposed to winter temperatures by producing too much biomass in the fall. Plants of open- pollinated (OP) cultivars tend to be smaller in aerial biomass, and their growing tips are less susceptible to freezing temperatures. As a result, the flowering spikes and racemes emerge in early spring with less yield loss due to freeze or extremely cold weather, however with more limited yield potential than the hybrids.

Climate fluctuations have exacerbated the temperature extremes during winter months, especially for continental climates of the United States, with very bitter cold followed by warming to unprecedented highs [14]. Warm spring and early summer weather in the Mid-South have caused higher than average temperatures during certain critical weeks of canola production. Therefore, the latest dates desirable for winter canola to mature in the region are May and June [13]. This is especially true when winter canola precedes a summer row crops like corn, cotton, sorghum, and soybeans that must be planted before June.

Despite these issues, winter canola has a large potential in the Southeast especially as a new commercial oilseed crop, but also as a locally produced biodiesel [15], or in the future even as a sustainable aviation fuel source under demand by airlines facing the high costs of jet fuel [16].

For this study, we tested germplasm in Tennessee that was developed at Alabama A&M University (Huntsville in Northern Alabama) and Virginia State University (Petersburg, central Virgina). The region is at the heart of the mid-South; mid-way between the deep South and the mid-West. The growing conditions in this area require canola varieties that are locally adapted and winter-hardy, although in some seasons, snow protects growing plants from low-temperature damage [12] [17] [18]. Crops of canola can also be used as food plots for wildlife [19], and after oil is pressed the canola residues are a high protein feed cake for cattle [12] [20]. Winter canola is also an effective cover crop with nematocidal and weed control properties [18].

Our goal for this study was to compare the publicly bred, early-maturing winter canola germplasm from Alabama A&M University (AAMU) to other check varieties of open-pollinated (OP) canola from further north (Virginia State University, VSU and Kansas State University, KSU) both for yield potential and oil and protein content. Early maturing canola should be sufficiently high yielding to be of interest for double cropping with some summer crops in the South. Such lines would be very valuable for producers interested in diversifying their row crop agriculture in the Southeast and Mid-South regions and producing a valuable winter crop to make use of, cover, and protect their fields.

## 2. Materials and Methods

### 2.1. Plant Materials

A total of 18 lines from Alabama A&M University (AAMU) were selected for earliness to flower and adaptation to growing conditions in Northern Alabama [21]. They are equivalent to the early maturity lines evaluated as a cabbage seedpod weevil trap crop at AAMU [22]. These will be called the AAMU lines from here on in and are numbered consecutively. Three Kansas State University (KSU) varieties [23] from the National Winter Canola Variety trial (NWCVT) were also planted in one of the seasons. These were the cultivars "Riley", "Sumner" and "Wichita", all later maturing with high potential yields of oil and harvestable seeds. They served as checks for the earliness of the Southern-bred AAMU genotypes. In addition, another Southeastern winter canola genotype named "Virginia", was sourced from Virginia State University (VSU), was planted across both seasons and was expected to be of more intermediate maturity than the three other checks [24].

### 2.2. Planting Location and Design

The experiments were conducted at the Agricultural Research and Education Center of Tennessee State University in Nashville, TN (36.1758 N - 86.8261 W). The soil type was Armour silt loam, with 2 to 5 percent slope, pH of 5.8 to 6.0 and sufficient phosphorus, and potassium which is typical of floodplain soils in the Cumberland River Valley. Plots were fertilized by rotations with legumes in the previous summers. The experiments were planted as replicated randomized complete block design (RCBD) trials. RCBD in season 1 was planted in the fall of 2015 and harvested in the spring of 2016 and RCBD in season 2 was planted in fall of 2016 and harvested in the spring of 2017. Both years' experiments had 4 replicates as blocks. Original seed was used in each season but seed for AAMU18 in the second season was insufficient, so that plot was not planted that year nor were checks.

### 2.3. Experimental Plots and Phenological Traits

Plots consisted of four rows planted at a double row spacing of 12 inches between rows and 16 inches between doubles. In the first season, plot size was 4.2 $m^2$ with dimensions of 2.4 m × 1.74 m (7.8 ft × 5.75 ft); while in the second season the plot lengths were slightly increased to 3.1 m (10 ft.) with the same width and a total size of 5.4 $m^2$. Planting dates were October 10 and 15, respectively for the two seasons. For phenological measurements, we took data by visual observation of times to mid-flowering (50% yellow blooms), final flowering (100%), and full maturity, calculated in days after planting (DAP). Drone fly overs were conducted in the second season for capturing earliness in the spring flowering percentage. The drone used was the DJI Phantom UAV (DJI Inc., Shenzhen, China) flown in late March by a TSU specialist. Image capture was as JPEG image files at 80 feet (24.4

m) above the field level. Analysis of the amount of flowering per plot was done from photos based on a percentage scale ranging from no flowering (0%) to full flowering (100%).

### 2.4. Harvest for Yield, Protein, and Oil Determination

Plots were harvested at maturity between May 15 and June 1 of each year using a sickle mower adapted to a BCS tiller (Oregon City, OR) to break the stem of the plants at their base. The inside two rows of each four-row plot were harvested. Whole plants were bundled and bagged into plastic bushel bags that were lightly crushed to release pods. The bags were dried for a week on a hoop house bench. An Almaco LPT15 (Nevada, IA) gasoline-powered thresher was used to initially clean the seed harvest. Cleaning was performed on a Clipper Airscreen (Seedboro Inc., Des Plaines, IL) and a separation table was used with a sieve size of 2.5 mm to obtain pure canola seed. A total of 10 g of the cleaned seed was weighted as a sample for Near Infrared Spectroscopy (NIRs) analysis, which was conducted at Kansas State University. Protein and oil percentages were measured on a 5% moisture basis using standard calibrations for a Perten model DA7250 analyzer (PerkinElmer, Waltham, MA). Seed moisture was not significantly different between varieties before NIRS.

### 2.5. Data Analysis

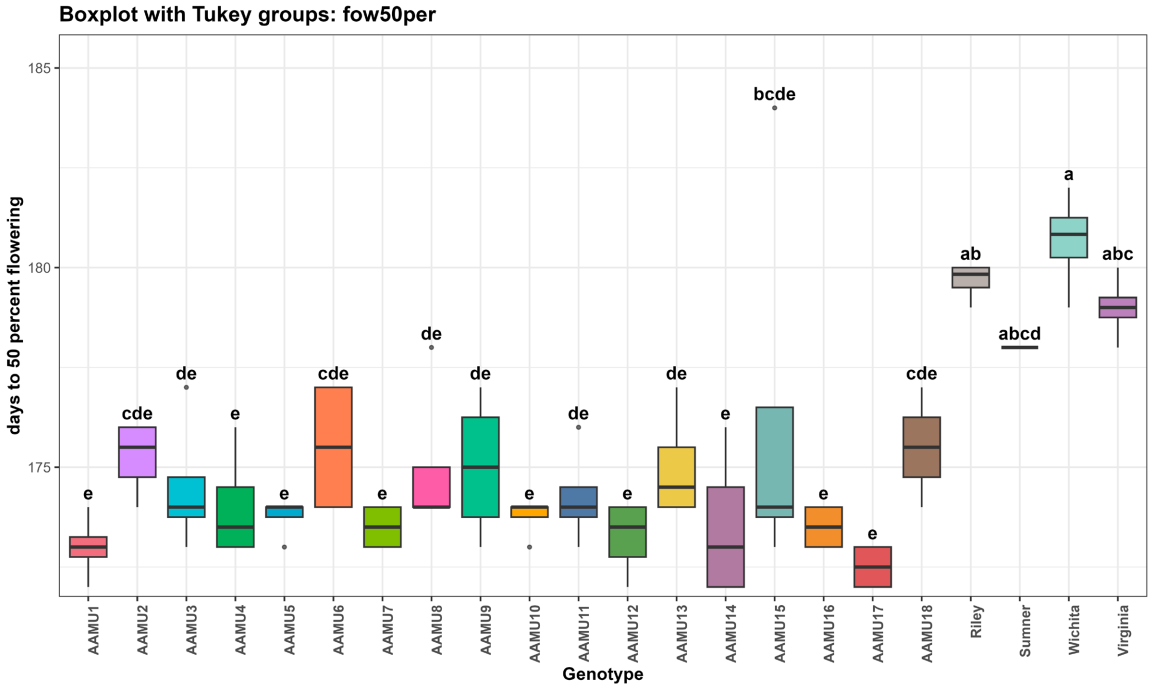
Analysis of variance (ANOVA) was conducted using R software v. 4.5.2 [25] assuming genotype as fixed treatment effect and replication as a blocking factor. Data from two years were analyzed separately, and genotype × year interaction was not evaluated because of an unbalanced number of genotypes. For each trait, the analyses were performed using available observations. Missing values were excluded on a trait-by-trait basis. Standard deviation (SD) calculations were based on [26]. Averages ± SD were graphed with different letters above box plots or within table columns representing significant differences from a Tukey's HSD multiple comparison test for the genotypes as a *post hoc* test after the ANOVA. Correlation analysis among traits were made in R each year separately using Pearsons's correlation with all available observations.

## 3. Results

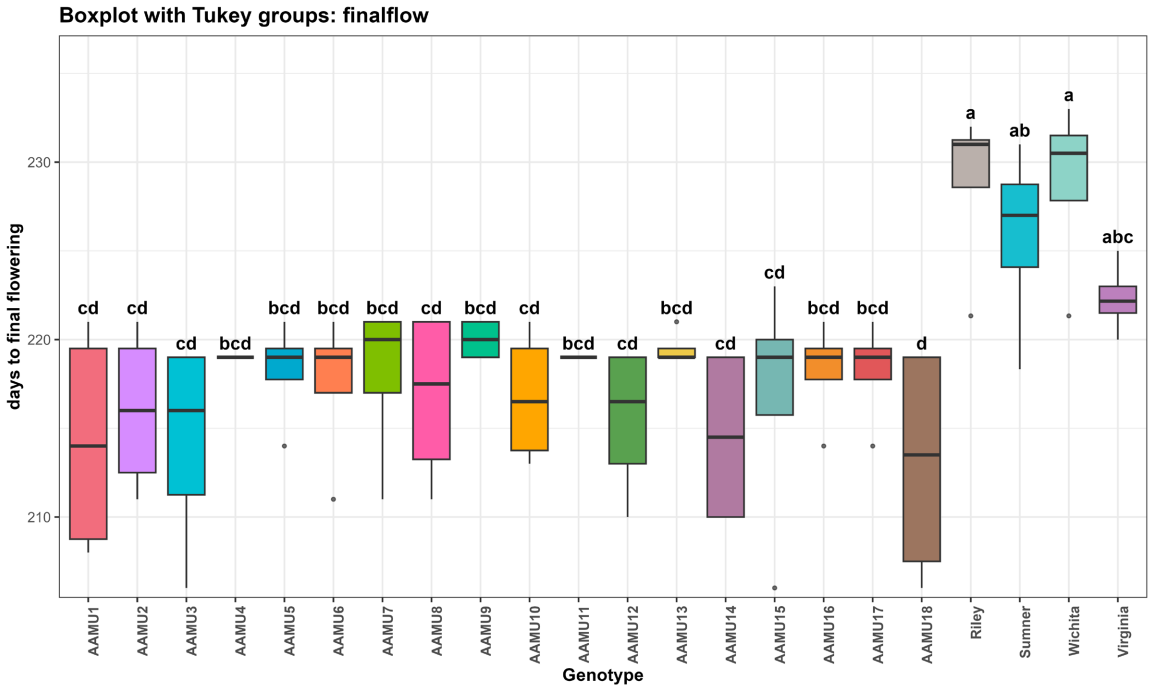
### 3.1. Earliness Differences

Significant variability in phenology of winter canola was observed for the AAMU lines [22], according to ANOVA results, as was expected from their breeding and selection history. These lines were earlier to flower and mature than all the check varieties, especially those from KSU such as Riley [27], Sumner [23], and Wichita [28]. Meanwhile, the cultivar Virginia [29] listed as VSU on the figures and tables was intermediate. In season one, the average time to 50% flowering for all the AAMU lines was 174.3 DAP which was earlier than the three KSU genotypes but slightly later than VSU (**Figure 1**).

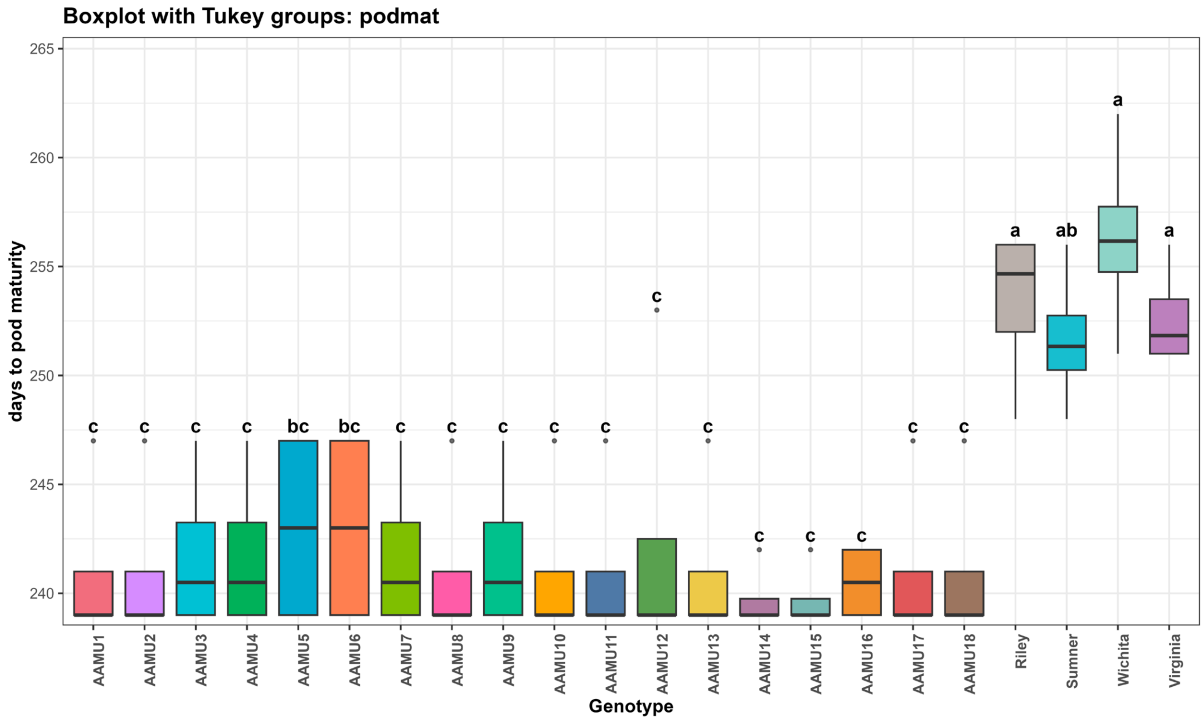
The range was 172.5 to 176.3 DAP. For time to 100% flowering, the average was 217.0 DAP, which was equivalent to cultivar Sumner, and ranged from 213.0 for AAMU18 to 219.5 for AAMU13. Days to maturity averaged 241.3 for the AAMU lines ranging from 239.8 to 241.0 DAP. Most AAMU lines were significantly earlier than the KSU lines and the VSU genotype.



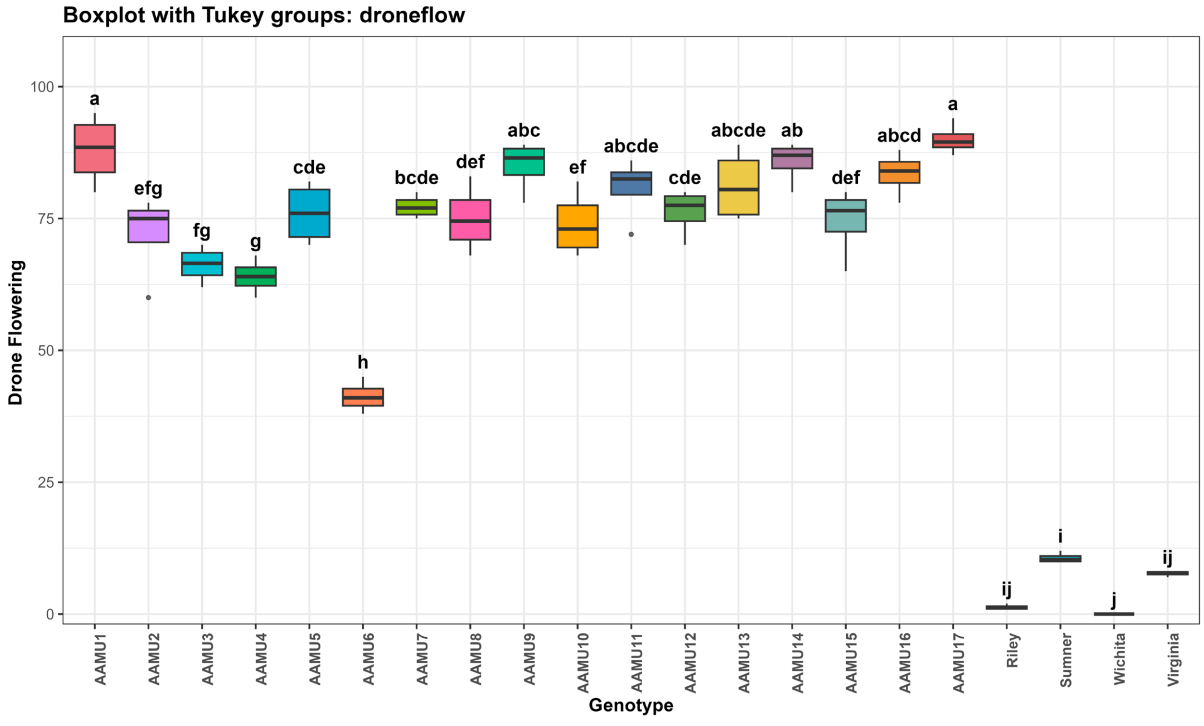

(a)




(b)




(c)




(d)

**Figure 1.** Phenological traits measured for winter canola in days after planting (DAP) and percentage flowering (%F) for germplasm including Alabama A&M University (AAMU) lines and the check varieties Riley, Sumner and Wichita (KSU) or Virginia (VSU) grown at the Tennessee State University farm in Nashville, TN over two seasons, For first season the following traits are shown: (a) days to 50% flowering in DAP; (b) days to final flowering in DAP; and (c) days to pod maturity in DAP. For the second season, (d) drone flowering calculation in %F is shown.

The flowering percentage calculated by drone in the second season varied from 41.3% to 90.0% for AAMU lines and averaged 75.93% overall for these genotypes. The VSU line, in contrast, averaged only 10.0% flowering at the same time, and all KSU lines were 0% or not flowering at all during the drone flight.

### 3.2. Seed Yield

Significant effects of genotype were observed for yield in the first year, but not in the second year. Seed yield results varied based on the genotypes analyzed (Table 1). The KSU variety Sumner was the highest yielding of all genotypes (3018 Kg·ha$^{-1}$) followed by the variety Wichita (2569 Kg·ha$^{-1}$). The highest overall average yield among AAMU lines was 2348 Kg·ha$^{-1}$ for AAMU2 in year 1. Meanwhile, in year 2, the highest yield among the AAMU lines was 1810 Kg·ha$^{-1}$ for AAMU8. Lowest yields among the AAMU lines were 912 Kg·ha$^{-1}$ in the first season, and 936 Kg·ha$^{-1}$ in the second season. The VSU genotype yielded 1714 Kg·ha$^{-1}$ and 1275 Kg·ha$^{-1}$, in the two seasons, respectively. AAMU2 and AAMU18 yielded above 2000 Kg·ha$^{-1}$ in the first season, and together with AAMU8 in the second season produced higher yields than VSU. Seed was not available from AAMU18 or the KSU checks for the second season and therefore a combined analysis was not done.

**Table 1.** Seed yield of winter canola in kilograms per hectare (Kg·ha$^{-1}$) along with seed oil and seed protein in percentage (%) for germplasm from Alabama A&M University (AAMU) and the check varieties Riley and Sumner (KSU) or Virginia (VSU) grown at the Tennessee State University experimental farm in Nashville, TN over two years (Yr.).

| Germplasm Entry | Seed Yield (kg/ha) | | Seed Oil (%) | | Seed Protein (%) | |
|---|---|---|---|---|---|---|
| | Yr 1 | Yr 2 | Yr 1 | Yr 2 | Yr 1 | Yr 2 |
| AAMU 01 | 1297$^{bc}$ | 935$^{a}$ | 42.4$^{a}$ | 40.6$^{a}$ | 22.8$^{abcd}$ | 24.3$^{a}$ |
| AAMU 02 | 2348$^{abc}$ | 1677$^{a}$ | 41.1$^{a}$ | 40.7$^{a}$ | 22.9$^{abc}$ | 24.4$^{a}$ |
| AAMU 03 | 1578$^{abc}$ | 1170$^{a}$ | 41.8$^{a}$ | 41.5$^{a}$ | 22.7$^{abcd}$ | 23.6$^{a}$ |
| AAMU 04 | 1527$^{abc}$ | 999$^{a}$ | 42.9$^{a}$ | 40.6$^{a}$ | 22.1$^{ab}$ | 24.6$^{a}$ |
| AAMU 05 | 1437$^{bc}$ | 1155$^{a}$ | n/a$^{a}$ | 40.9$^{a}$ | n/a$^{abcd}$ | 23.9$^{a}$ |
| AAMU 06 | 1677$^{abc}$ | 1268$^{a}$ | 41.6$^{a}$ | 41.6$^{a}$ | 22.2$^{abcd}$ | 23.8$^{a}$ |
| AAMU 07 | 1217$^{bc}$ | 1241$^{a}$ | 42.0$^{a}$ | 40.9$^{a}$ | 23.0$^{abcd}$ | 24.2$^{a}$ |
| AAMU 08 | 1780$^{abc}$ | 1810$^{a}$ | 41.9$^{a}$ | 41.0$^{a}$ | 23.3$^{abcs}$ | 24.1$^{a}$ |
| AAMU 09 | 1171$^{bc}$ | 1432$^{a}$ | 41.5$^{a}$ | 41.3$^{a}$ | 22.7$^{abcd}$ | 23.9$^{a}$ |
| AAMU 10 | 1930$^{abc}$ | 1479$^{a}$ | 41.6$^{a}$ | 41.4$^{a}$ | 23.1$^{abcd}$ | 23.8 |
| AAMU 11 | 911$^{c}$ | 1030$^{a}$ | 42.3$^{a}$ | 41.2$^{a}$ | 23.3$^{abcd}$ | 24.2$^{a}$ |
| AAMU 12 | 1610$^{abc}$ | 1144$^{a}$ | 41.7$^{a}$ | 40.9$^{a}$ | 22.8$^{abc}$ | 24.4$^{a}$ |
| AAMU 13 | 1809$^{abc}$ | 1611$^{a}$ | 41.7$^{a}$ | 40.5$^{a}$ | 22.6$^{abc}$ | 24.5$^{a}$ |

**Continued**

| | | | | | | |
|---|---|---|---|---|---|---|
| AAMU 14 | 1383$^{bc}$ | 1157$^{a}$ | 40.9$^{a}$ | 40.8$^{a}$ | 22.7$^{abcd}$ | 23.3$^{a}$ |
| AAMU 15 | 1094$^{bc}$ | 945$^{a}$ | 42.5$^{a}$ | 40.6$^{a}$ | 22.9$^{abc}$ | 24.4$^{a}$ |
| AAMU 16 | 1335$^{bc}$ | 1050$^{a}$ | 42.1$^{a}$ | 40.8$^{a}$ | 23.0$^{abc}$ | 24.4$^{a}$ |
| AAMU 17 | 1211$^{bc}$ | 1345$^{a}$ | 41.3$^{a}$ | 41.2$^{a}$ | 23.5$^{abc}$ | 24.4$^{a}$ |
| AAMU 18 | 2124$^{abc}$ | n/a | n/a | n/a | n/a$^{abc}$ | n/a |
| KSU Riley | 2306$^{abc}$ | n/a | 402$^{a}$ | n/a | 22.9$^{cd}$ | n/a |
| KSU Sumner | 3018$^{a}$ | n/a | 41.7$^{a}$ | n/a | 22.7$^{d}$ | n/a |
| KSU Wichita | 2569$^{ab}$ | n/a | 37.3$^{b}$ | n/a | 24.8$^{a}$ | n/a |
| VSU Virginia | 1713$^{abc}$ | 1275$^{a}$ | 41.7$^{a}$ | n/a | 23.1$^{bcd}$ | n/a |
| Avg. AAMU | 1525$^{n/a}$ | 1262 | 41.84$^{n/a}$ | 40.99 | 22.83$^{n/a}$ | 24.13 |

a. Compact letter display used to summarize outcome of multiple comparison of means for each trait based on Tukey's HSD test with alpha level of 0.05 where groups sharing a letter are statistically indistinguishable.

### 3.3. Canola Seed Composition Traits

Oil and protein averaged 42% and 23%, respectively, in the initial sample from season one. The values ranged from 40% to 43% for oil and from 22% to 23% for protein (Table 1, Figure 2). The averages of oil and protein for the AAMU lines were 41% and 24% in the second season, respectively. Oil among the AAMU1 through AAMU17 lines ranged from 40% to 42% in the second season. Protein for AAMU lines ranged from 22% to 24% in the first season compared to 23% to 25% in the second season. Correlations were negative and highly significant between protein and oil when considering the AAMU lines in season 2 ($r = -0.72$) but less significant when considering their values across all genotypes in season 1 ($r = -0.18$). Example of a genotype with lower oil but high protein was AAUMU15. Other lines were intermediate.

### 3.4. Correlations between Yield and Seed Composition Traits

Yields were significantly and positively correlated between the seasons ($r = 0.67$); however, they averaged lower in season 2 than in season 1. The population distributions of yield and composition traits for the AAMU and VSU lines in the experiments can be seen to vary between seasons (Figure 2). When seed yield was low in the second season, the oil distribution was in a lower range even while the protein was in a higher range. Correlations between yield and the compositional characteristics were moderate but notable, with protein concentration negatively correlated with yield in both seasons compared to oil concentration which was negatively associated in season one but positively associated with yield in season two. The correlation of these traits and phenology are discussed in the next section, where earliness was seen to command a yield penalty. In any case yield may have varied due to weather conditions in the two years (Figure 3).

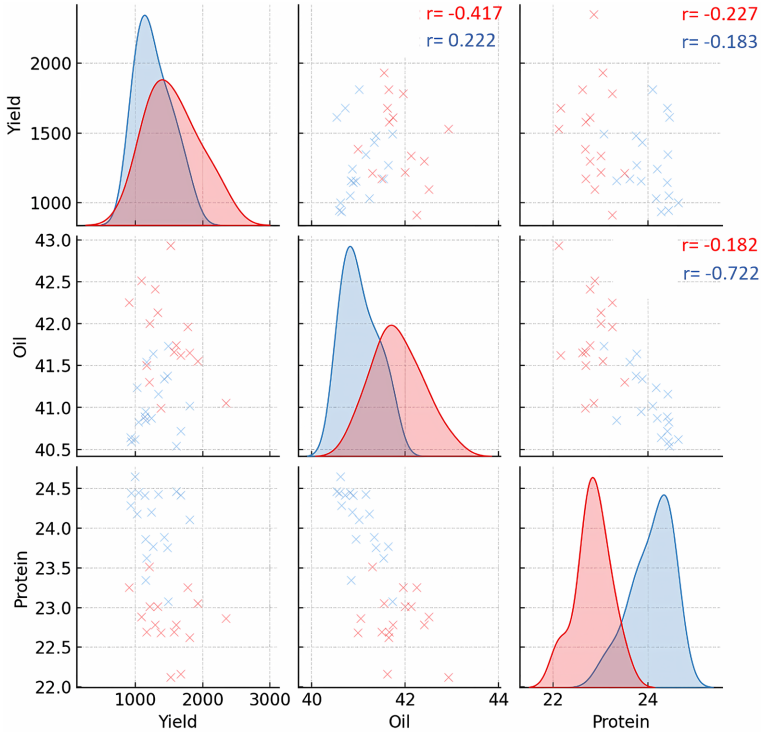



**Figure 2.** Correlations between yields, oil percentage and protein percentage for winter canola for AAMU and VSU germplasm planted in Nashville at the TSU farm over two seasons. Numbers, histograms and graph symbols in red indicate first season, blue indicates second season.

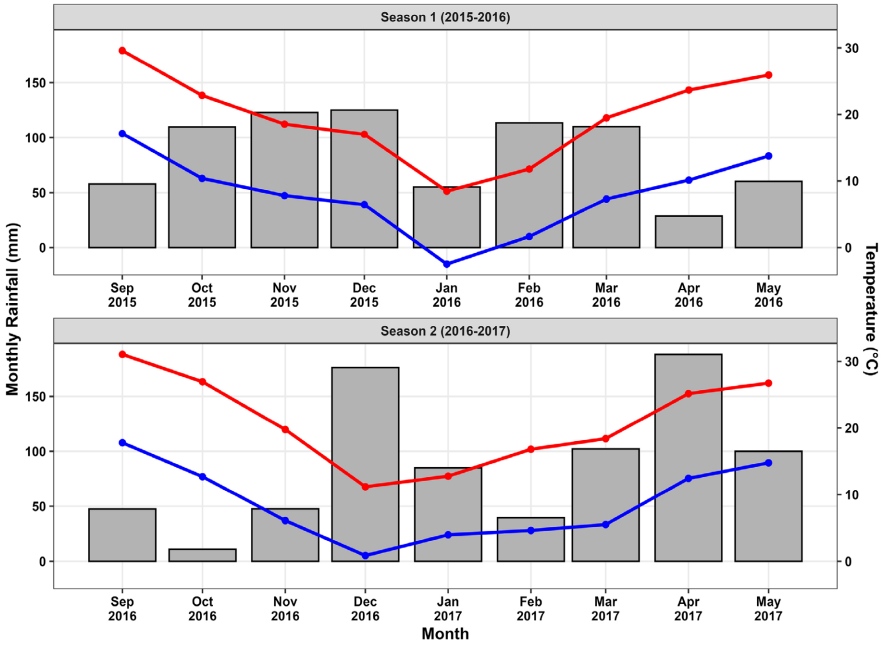



**Figure 3.** Monthly rainfall and temperature tend during season 1 (2015-2016) and season 2 (2016 to 2017) field growing seasons for winter canola. Rainfall indicated by gray bars and are in millimeters (mm), while temperature in ˚C are showing in red (maximum) and blue (minimum) lines, respectively. Data from National Oceanic and Atmospheric Administration (NOAA), National Centers for Environmental Information (NCEI) [30].

### 3.5. Correlations of Yield and Phenological Traits

The correlations between phenological variables in the first season with yield, oil and protein are graphed below (Figure 4). The evaluations for flowering at 50% (mid) and 100% (final) were correlated with each other as were these two parameters with pod maturity (r = 0.70 and r = 0.69, respectively) like mid and final flowering (r = 0.61) with each other (see blue in figure below). The findings of significant correlations between phenology and yield are represented by yield and mid-flowering (r = 0.43) as well as yield and pod maturity (r = 0.33). Oil and protein contents were somewhat negatively correlated (see red in figure below) with some phenological traits. In other cases, depending on the trait considered, the correlations were positive (see blue in figure below), with the significance of the Pearson correlations expressed in the lower left diagonal of the quadrant and the r-values of Pearson correlations in the upper right diagonal of the quadrant.

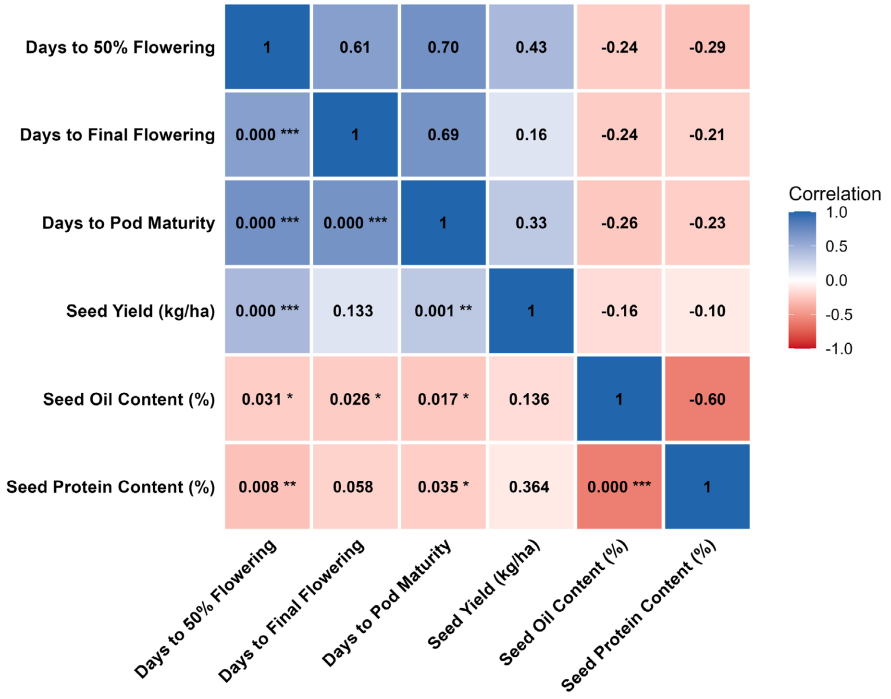



Figure 4. Pearson correlations between phenological traits and yield, oil percentage and protein percentage for winter canola for AAMU, KSU and VSU germplasm planted in Nashville at the Tennessee State University farm in the first season. The symbols *, **, *** represent probability significance levels of 0.1, 0.05, 0.01 and 0.001.

## 4. Discussion

In this study, we found that certain early maturing winter canola lines from AAMU and VSU as well as later maturing ones from KSU were well adapted to middle Tennessee, similar to what was found by other researchers testing only KSU lines [10] [12]. This is not surprising as other *Brassica* species, especially leafy vegetable greens such as collards, mustards, and kale are adapted to fall planting in the mid-South [21] [31] [32].

However, like other *Brassicas*, the main abiotic factors for winter canola to overcome are cold stresses [33]. Sudden freezes can severely damage the growing tip of the plants even if the stem and roots of canola are well established [34]. With the similar planting dates of mid-October we used for both seasons, the differences between years were likely due to winter weather conditions, with several early winter freezes affecting survival and drought in fall affecting establishment. This may also have affected earliness to flower. For example, an early spring thaw in the first season could have sped up the flowering compared to freezes in the second season.

Cold hardiness and adaptation to temperature fluctuations is required for canola in middle TN where very cold night temperatures in spring are common and where snow cover protection is rare. Secchi *et al.* [8] concluded that winter conditions can be very challenging for canola to grow between 35˚N and 40˚N latitude, as we found especially when continental weather is variable. Breeding of winter canola certainly requires selection of cold tolerance [20]. In addition, plant phenology in terms of dates of early flowering and maturity is important to winter survival and overall productivity.

Early in our experimentation with the Southeastern-adapted lines, we noticed differences in earliness, especially for AAMU lines which were early flowering when compared to KSU lines. Their earliness was noted by Sangireddy *et al.* [22] in Northern Alabama. We also found that the early lines generally yielded less than later maturing ones. Flower evaluations showed that AAMU lines were early both in bud and pod raceme production. This made them more susceptible to cold snaps than KSU lines in season one. VSU, which flowered moderately early, yielded well. KSU lines being later, yielded even better than AAMU or VSU genotypes in season 1. The missing AAMU18 entry and absent KSU checks in season 2 affected year-to-year comparisons, but overall, we had enough entries to draw the conclusion that earliness affected yield, despite different weather each year.

Other factors affecting yield in canola can be date of planting [9] [10] [35] [36], fertilization [37]-[39] plot biomass and soil coverage [12], as well as how much flower abortion, pod drop, and shattering the variety presents [40], or how long the plant flowers in the springtime [17]. Top yields in winter canola can be over 3500 $Kg{\cdot}ha^{-1}$ using hybrid and GMO cultivars under seasons of favorable weather with dedicated agronomic management [9] [20] [36]. In this trial, AAMU lines were lower yielding due to their earliness but could be useful as low-input crop or as a rotation for double-crops, summer species due to their speedy harvest, allowing a full season of growth for the second crop in the rotation.

Oil content of canola is among the most important traits for canola and usually is in the range of 40% for the summer crop grown in North Dakota [40] and similar but more variable for the winter crop in Virginia [24] [29] [41] or Tennessee [10]. In the lower yielding production environment of the Southeast compared to Northern Plains, the oil percentage has ranged as low as 37% and as high as 48%. Meanwhile, the protein content of winter canola in Tennessee has been found to

be around 21% [12], like our results. We also found negative correlations between oil and protein first observed in Tennessee by [10]. We also found tentative but not strict oil and protein relationships to yield. Another result we can highlight was the utility of a UAV drone canola for monitoring early flowering in the second season. With that application we expand the use of UAV technology for agricultural monitoring as described before for our region of the United States [42].

In terms of agricultural productivity, the maximum yields for winter canola we observed for both years of 2000 plus kg/ha showed promise for local agriculture in Tennessee as it confirmed yields found in other OP varieties tested by [12]; although our yield was somewhat lower than those of winter canola hybrids used by Tetteh *et al.* [10] perhaps due to the genetics but also the weather and site conditions.

The information found for early canola in this study could be useful in various other parts of the mid-South of the United States, namely in the Mississippi watershed and then more generally across the Eastern U.S. seaboard to the Mid-Atlantic states. However, the single-location design and two-season scope of our study mean that validation by on-farm and additional experimental station sites would be useful before extending our results to the broader Southeast region. One method to do this would be to include some of the best AAMU lines in further testing of the NWCVT organized by Kansas State University or by placing them in cross-species nurseries of the National Cover Crop Variety Testing system organized by the USDA-CAP project on winter cover crops.

Southeastern states with humid climates, such as Georgia, have recommended protocols for production of winter canola [6], but would benefit from testing of early maturing lines that would allow a wider range of crop rotations. Kentucky has studied double cropping soybean after canola [43]. These states have similar climates to the ones represented by the germplasm developed for this study and all could benefit from the lines tested. Finally, the germplasm described here are non-genetically modified organisms (non-GMO) and could fit into organic production systems before or after vegetables in innovative small farm rotations.

In conclusion, the early maturing germplasm from this study could be useful across a broader region of similar latitudes in the various US regions. Overall, the AAMU lines were variable in yield but due to their earliness are promising for production in double cropping systems for similar regions, and this monitoring could be done by a UAV as we proved in this study. The VSU line had good yield but could be outdone by the KSU varieties used as checks, but this was a tentative conclusion based on the lines tested in the first-year check set that were not available for the second year. All the AAMU genotypes tested were open pollinated (OP) and could be distributed without intellectual property constraints and therefore could be used by farmers for seed saving, although this can introduce some variability into the cultivar compared to pure hybrids. The principal advantage to the AAMU lines as well as the VSU variety, therefore, would be their earliness to maturity which would allow rotation with other crops.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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