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Optimizing faba bean cultivation: assessing varietal performance in spring and fall

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The need to identify specialty crops in Virginia has driven interest in faba beans (*Vicia faba* L.), which offer potential benefits for crop rotation systems. As a cool-season crop, faba beans can be planted in both fall and spring, providing flexibility in farming schedules. A field study was conducted at Randolph Farm, the Virginia State University Research and Extension Farm, using a completely randomized factorial block design. This study examines the performance of seven faba bean varieties—Ethiopia, NEB247, Aprovecho, EN3, EN47, Windsor and EN45—across three spring (late February, late March and mid April), and three fall (late September, early October and late October) planting dates. Our results demonstrate that both variety and planting date significantly influence the yield and yield components of faba beans. Among the varieties tested, Windsor and EN47 exhibited superior traits across multiple categories, making them preferable for achieving high yields. Conversely, varieties such as EN45, Aprovecho, and NEB247 showed poor performance. Fall planting dates generally resulted in superior growth, yield, and maturity characteristics, underscoring their importance for maximizing faba bean production. We observed that faba beans planted in the fall had 58% more branches, 100% more shoot dry matter, 34% higher 100-seed weight, double the grain yields, and 8% higher harvest index compared to those planted in the spring. To further enhance faba bean production, additional studies are suggested to clarify the physiological relationships between photosynthesis rates and the sink-source dynamics. Furthermore, investigating how planting dates impact the nutrient components of faba beans will provide deeper insights into optimizing their cultivation.

KEYWORDS

grain yield, harvest index, pod yield, Windsor, 100-seed weight

1 Introduction

Faba bean (*Vicia faba*), also known as broad bean or horse bean, is grown worldwide in cropping systems as a grain (pulse) and green-manure legume. It is the fourth most important pulse crop in the world and a popular vegetable in the Middle East and Europe, though uncommon in the U.S. In 2020, the world production of faba beans reached 5.67 million metric tons, a significant increase from 4.35 million metric tons in 1990. Major producers of faba beans include China, Ethiopia, France, Egypt, and Australia (Akibode and Maredia, 2012). Faba beans have been cultivated for thousands of years and are valued for their high protein content, nitrogen-fixing ability, and adaptability to various climatic conditions (Stoddard et al., 2010). As a legume, faba beans play a crucial role in sustainable agriculture by improving soil fertility and reducing the need for synthetic fertilizers (Crews and Peoples, 2005). In recent years, there has been a resurgence of interest in faba beans due to their potential to contribute to food security and environmental sustainability (Duc et al., 2015). Faba beans contain almost twice the protein content as cereal grains, with globulins (60%), albumins (20%), glutelins (15%), and prolamins (8%) (Rahate et al., 2021). Faba bean possesses high protein content from 20% to 41%; the wide variations are due to varietal differences and the source type, that is, flour, fraction, or isolate, as well as fertilization method, growth season, and planting site. In comparison with other beans such as lima, pinto, and red kidney beans, faba bean flour had the highest protein content of 29.76% (Gu et al., 2020).

Virginia, with its diverse climatic conditions and soil types, presents a unique opportunity to study the performance of different faba bean varieties under varying planting dates. The state's climate ranges from humid subtropical in the southeast to humid continental in the northwest, providing a broad spectrum of growing conditions (Cathey, 1990). The current state of crop rotation practices in Virginia's agricultural sector presents significant challenges for farmers. The predominant reliance on crops like rye, corn, hay, or grass has proven to be economically unviable for many growers. This limited diversification not only hampers farmers' profitability but also contributes to suboptimal soil health, making the agricultural systems more susceptible to diseases, pests, and weeds. The integration of alternative crops, such as faba beans, into the rotation systems could address these issues. However, the successful cultivation and marketing of faba beans depend on identifying the optimum planting dates and suitable varieties. Sowing date is a crucial determinant of crop yield, which is essential for increasing the productivity of various agronomic crops (Joshi et al., 2017; Refay, 2001; Wani et al., 2018). The recommendation for an optimal planting date depends on a combination of factors, including plant variety, temperature suitability, and water availability (Balalić et al., 2012). Environmental factors significantly influence plant growth and yield components, making the sowing date pivotal for sustainable grain yield and quality (Abbas et al., 2019). Adapting an optimum planting date is particularly important for new crops introduced to a region, ensuring favorable growing conditions.

The faba bean, a cool-season annual legume (Jensen et al., 2010), exemplifies this necessity. In California, it is typically planted in February and March for vegetable use and from September to November for cover crops. The temperature range for growth is 5–35°C with an optimum temperature for photosynthesis of 25°C. Flowering is destroyed by frost, and few cultivars can tolerate temperatures<−10°C (Boote et al., 2002; Mínguez and Rubiales, 2021). Current faba bean cultivars are categorized in two main ways. First, they are classified as spring, Mediterranean, and winter types based on their vernalization requirements for flowering—none, mild, or strong, respectively. This classification allows for adaptation to various climates: spring types for cold and warm regions, Mediterranean types for areas without severe winters, and winter types for regions with cold winters that do not severely harm the crop. Second, cultivars are categorized by growth habit as indeterminate, semideterminate, and determinate, corresponding to long, short, and no vegetative growth after the last flower, respectively (Mínguez and Rubiales, 2021). Therefore, the choice between winter and spring faba beans heavily depends on variety, climate, soil type, and cropping system. Winter beans utilize autumn and winter moisture and mature early. Conversely, spring beans, vulnerable to summer drought, depend on early summer precipitation for high yields, making early sowing critical (Zhao et al., 2024). Planting date affects the phenological development of faba beans and their exposure to various biotic and abiotic stresses, such as temperature fluctuations, disease pressure, and pest infestations. Spring planting generally exposes crops to warmer temperatures and longer day lengths, enhancing vegetative growth and yield potential (Link et al., 1996). Conversely, fall planting can take advantage of cooler temperatures and reduced disease pressure but leaves crops more vulnerable to frost and shorter growing periods (Stoddard et al., 2010). Previous research underscores that genetic diversity within faba beans significantly influences their performance under different environmental conditions (Temesgen et al., 2015).

This study aims to investigate the performance of different faba bean varieties under varying spring and fall planting dates in Virginia, and it is the first to evaluate the combined effects of these factors on agronomic performance under local conditions. By systematically evaluating the growth characteristics, yield potential, and resilience of these varieties, the research seeks to identify optimal planting strategies that can enhance crop performance and sustainability.

2 Materials and methods

The experiment was conducted at Randolph Farm, the Virginia State University Research and Extension Farm in Chesterfield County, Virginia (37°13′43″ N; 77°26′2″ W) from 2023-2024. The study employed a completely randomized factorial block design with three replicates to evaluate the performance of seven faba bean varieties ('Ethiopia', 'NEB247', 'Aprovecho', 'EN3', 'EN47', 'Windsor' and 'EN45'). The study included three spring planting dates: February 24, 2023 and February 29, 2024 (late February), March 24, 2023 and March 21, 2024 (late March), and April 12, 2023 and April 12, 2024 (mid April). Additionally, three fall planting dates were used: September 22, 2023 (late September), October 6, 2023 (early October), and October 22, 2023 (late October). Table 1 presents the plant introduction numbers for various faba bean varieties planted at the Research and Extension Randolph Farm.

Data on monthly mean air temperature (°C) and monthly precipitation (mm) were provided by the Weather Underground (https://www.wunderground.com/history/monthly/us/va/petersburg) located at Richmond International Airport Station (Figure 1).

The soil was tilled with a disk to ensure it was soft and even for planting. Baseline soil conditions were established by collecting soil samples from the field before planting, with the results presented in Table 2. To manage weed pressure, pre-planting herbicides such as Treflan (trifluralin) and S-metolachlor (Dual II Magnum) were applied at a rate of 1100 ml ha^{-1} to control annual grasses and small-seeded broadleaf weeds. Fungicide Ridomil Gold® EC (Syngenta Crop Protection) at a rate of 1100 ml ha^{-1} was applied to control soilborne oomycete diseases.

Each experimental plot measured 1.6 m × 2.4 m, with an additional 1 m buffer zone. Two rows were hand-planted in each plot at a depth of 5 cm. The space between rows was 38 cm, and the space between plants within each row was 15 cm, resulting in a plant population of approximately 11 plants m^{-2}. No seed inoculation or irrigation was performed during the experiment. Before planting, seeds were treated with Vibrance Maxx Seed Treatment (Syngenta US) at a rate of 0.1 ml per 100 g of seed to protect against damage from various soilborne, seed-borne, and seedling diseases. Hand weeding was carried out throughout the growing seasons. After germination and once the plants were adequately established, 40 kg nitrogen ha^{-1} from urea, 30 kg P_2O_5 ha^{-1} from triple superphosphate, and 40 kg potassium ha^{-1} from K_2O were applied by hand throughout each plot. Urea was applied as a starter to promote early growth and nodulation, acknowledging faba bean's natural nitrogen-fixing ability. Throughout the growing season, data on germination, growth, performance, and days to harvest were recorded. Upon harvesting, yield and yield components were measured and documented. During the maturity stage, three plants were manually harvested from each plot between early March and early July 2024, and the average data for each plot was calculated. Samples were then bagged and dried in a Grieve forced-air oven at 65°C for 72 hours to obtain shoot and root dry weights and for further analysis. The shoot and root of each plant were weighed separately, and the number of branches was counted.

TABLE 1 Plant introduction of faba bean varieties planted at the Research and Extension Randolph Farm, Virginia State University.

Genotype	GRIN USA Plant Introduction
EN45	PI 655333
EN47	PI 568235
EN3	PI 254006
NEB247	PI 655333
Ethiophia	PI 371803
Windsor	PI 433531
Aprovecho	–

The number of pods per plant, pod weight per plant, number of seeds per pod, and number of seeds per plant were recorded. Yield per plant and yield per pod were obtained, and 100-seed weights were measured using a weighing scale. The harvest index was calculated using the equation:

$$Harvest\ \ index = \frac{Grain\ \ \ yield\ \ \ (g)}{Total\ \ \ shoot\ \ \ dry\ \ \ weight(g)} \times 100$$

According to our observations, the Aprovecho variety planted in mid-April and the NEB247 variety planted in mid-October died, resulting in no data for these varieties on those specific planting dates. Data from two years of spring plantings were pooled and analyzed together with data from a single fall planting date. A factorial randomized complete block design was employed, and a combined analysis of variance was conducted using SAS software (SAS Institute Inc, 2013). The least significant difference (LSD) at $P \leq 0.05$ was employed to compare the means in this study.

3 Results

3.1 Plant height

Analysis of variance indicated that both variety and planting date significantly ($P< 0.01$) affected the plant height of faba beans (Table 3). The comparison of mean values showed that Windsor (54.5 cm) and NEB247 (54.3 cm) had the highest plant heights, followed by Aprovecho (53 cm). Conversely, EN45 had the lowest plant height (32.5 cm) among the varieties. Across all varieties, faba beans planted in late September exhibited the highest plant heights. On average, fall planting dates resulted in greater growth and higher plant heights compared to spring planting dates. No interaction effects of variety and planting dates were observed (Table 3).

3.2 Shoot dry weight

The effects of variety and planting date on the shoot dry weight of faba bean samples are shown in Table 3. The maximum shoot dry matter was observed in Windsor (40 g), while EN45 had the lowest (7.96 g). According to the results presented in Table 3, the highest shoot dry matter was produced when faba beans were planted in late September. There was no significant difference in shoot dry matter between the spring planting dates (Table 3).

3.3 Day to maturity

As shown in Table 3, the maturity time of faba beans was significantly influenced by variety, planting date, and their interactions ($P< 0.01$). Regardless of planting date, NEB247 and Aprovecho had the longest maturity times, with 189 and 187 days, respectively. Conversely, EN3 and Windsor had the shortest maturity times, with 164 and 165 days, respectively. Faba beans planted in late September exhibited the longest maturity times (239 days) compared to other planting dates. However, mid-April

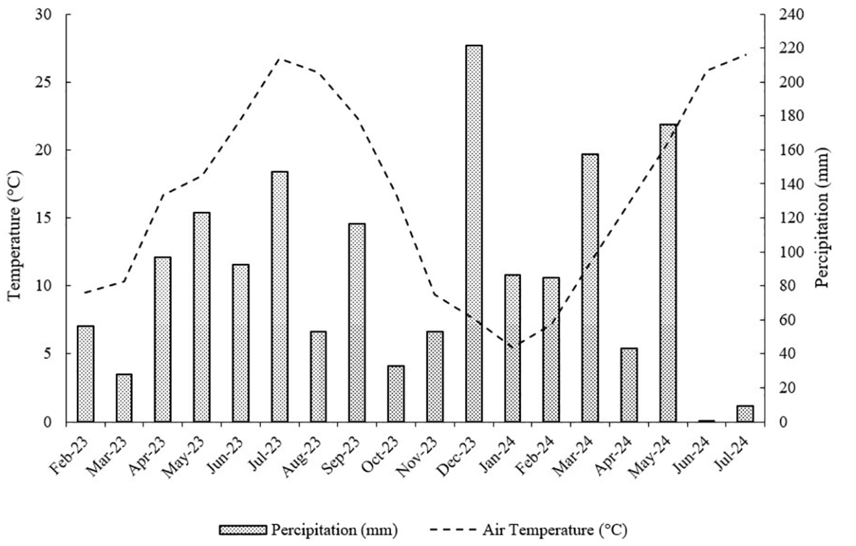

FIGURE 1
Mean air temperature and rainfall during the growing seasons (Feb 2023-May 2024), Virginia State University Randolph Farm, Petersburg, Virginia.

showed the shortest maturity time (89.3 days). On average, fall planting allowed for a longer growth period. Figure 2 illustrates the interactions between varieties and planting dates on maturity time. Across all varieties, the trend was consistent: late September planting resulted in the longest maturity time, while mid-April planting resulted in the shortest time to harvest.

3.4 Number of branches per plant

The number of branches in faba beans was significantly ($P< 0.01$) influenced by both variety and planting date (Table 3). Among the varieties, Aprovecho (3.83) and Windsor (3.54) had the highest number of branches. Across all varieties, faba beans planted in late September produced more branches compared to other planting dates. On average, fall planting resulted in a higher number of branches compared to spring planting dates (Table 3). There were no observed interaction effects between variety and planting dates.

3.5 Number of pods per plant

According to the ANOVA Table (3), the number of pods per plant was significantly affected by variety and planting dates ($P< 0.01$), and their interactions ($P< 0.05$). Between varieties, EN3 had the highest number of pods per plant (15.6); however, Aprovecho had the lowest (5.63). Across varieties, the highest number of pods per plant was recorded for plants planted late-Sep with 14.7. Conversely, the lowest number of pods per plant was related to mid-April, with 4.76 (Table 3). The bar chart illustrates the number of pods per plant for seven faba bean varieties across six planting dates, which include three fall plantings and three spring plantings. According to Figure 3, EN3 shows the highest number of pods per plant for late-Sep planting dates. The number of pods per plant in all varieties except NEB247 was higher in the fall compared to spring planting dates (Figure 3).

3.6 Pod weight per plant

The ANOVA results (Table 3) indicated significant effects of variety and planting dates on pod weight per plant ($P< 0.01$), with no observed interaction effects. Across all planting dates, Windsor exhibited the highest pod weight at 25.4 g, while EN45 showed the lowest at 5.73 g (Table 3). Faba beans planted in late September exhibited the highest pod weight at 20.4 g, which did not significantly differ from those planted in early October (19 g) and late October (18.2 g). In contrast, the lowest pod weight was observed for faba beans planted in late March at 7.45 g, which was statistically similar to those planted in mid-April and late March (10.5 g) (Table 3).

3.7 Number of seeds per pod

The number of seeds per pod was significantly influenced by both variety and planting dates ($P< 0.01$), with no significant

TABLE 2 Soil chemical properties at Randolph farm (Pre-planting analysis).

CEC	pH	Acidity	Base saturation	Organic matter	N	P	K	Ca	Mg	Zn	Mn	Cu	Fe	B
meq/100g		%			mg kg-1					ppm				
2	6.4	2	98	1.5	12	56	56	314	25	0.4	4.9	0.3	25.1	0.1

TABLE 3 Analysis of variance (*P* values) on the effects of variety, planting date, and their two-way interactions on faba bean growth, yield and yield components.

	Plant height (cm)	Shoot dry weight (g)	Day to maturity	Number of branches per plant	Number of pods per plant	Pod weight per plant	Number of seeds per pod	Number of seeds per plant	100-seed weight (g)	Yield per plant (g)	Yield per pod (g)	Harvest index (%)
Rep	ns	ns	ns	ns	ns	ns	ns	ns	0.01	ns	0.01	ns
Variety (V)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
Planting date (P)	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	<0.01	0.02	0.02	ns	<0.01
V * P	ns	ns	<0.01	ns	0.03	ns	ns	ns	ns	ns	ns	0.04
Variety												
Ethiopia	47.9^{BC}	15.6^{CD}	179^{C}	2.94^{AB}	7.87^{BCD}	8.61^{CD}	1.97^{B}	15.1^{BC}	39.2^{D}	6.27^{CD}	0.79^{CD}	38.2^{B}
NEB247	54.3^{A}	18.8^{BC}	189^{A}	3.24^{AB}	9.07^{BC}	9.08^{CD}	1.91^{B}	17.4^{BC}	36.6^{D}	6.38^{BCD}	0.74^{CD}	32.9^{BC}
Aprovecho	53.0^{AB}	26.4^{B}	187^{A}	3.83^{A}	5.63^{D}	11.4^{BCD}	2.01^{B}	10.2^{C}	56.3^{C}	8.02^{BCD}	1.73^{B}	30.5^{C}
EN3	46.8^{C}	19.5^{BC}	164^{E}	3.15^{AB}	15.6^{A}	12.7^{BC}	1.90^{B}	29.4^{A}	32.5^{D}	9.74^{BC}	0.63^{D}	51.1^{A}
EN47	41.4^{D}	21.0^{BC}	184^{B}	2.58^{B}	9.95^{B}	15.2^{B}	1.66^{B}	15.0^{BC}	73.6^{B}	11.0^{B}	1.30^{BC}	52.2^{A}
EN45	32.5^{E}	7.96^{D}	173^{D}	2.43^{B}	8.42^{BCD}	5.73^{D}	1.79^{B}	15.2^{BC}	27.1^{D}	4.37^{D}	0.54^{D}	48.9^{A}
Windsor	54.5^{A}	40.0^{A}	165^{E}	3.54^{A}	6.64^{CD}	25.4^{A}	3.03^{A}	20.3^{B}	93.5^{A}	18.7^{A}	2.89^{A}	46.5^{A}
Planting date												
Late February	43.5^{C}	15.0^{C}	109^{D}	1.74^{C}	8.21^{B}	10.5^{B}	2.05^{C}	15.5^{BC}	52.0^{B}	7.88^{B}	1.12	50.8^{A}
Late March	44.7^{BC}	13.8^{C}	95.1^{E}	2.27^{C}	6.49^{C}	7.45^{B}	1.93^{C}	12.5^{C}	44.4^{B}	5.33^{B}	1.04	37.5^{B}
Mid-April	42.6^{C}	18.0^{C}	89.3^{F}	3.21^{B}	4.76^{C}	10.5^{B}	2.24^{BC}	11.4^{C}	54.8^{B}	7.65^{B}	1.41	36.0^{B}
Late September	55.0^{A}	39.6^{A}	239^{A}	6.03^{A}	14.7^{A}	20.4^{A}	1.918^{C}	26.3^{A}	52.9^{B}	14.2^{A}	1.28	34.5^{B}
Early October	48.9^{B}	28.2^{B}	229^{B}	3.21^{B}	8.50^{B}	19.0^{A}	2.45^{AB}	20.5^{AB}	73.7^{A}	14.6^{A}	2.00	49.6^{A}
Late October	47.2^{BC}	27.1^{B}	218^{C}	2.24^{C}	6.68^{C}	18.2^{A}	2.64^{A}	17.4^{BC}	76.0^{A}	13.4^{A}	2.16	50.6^{A}

Different letters within columns in each parameter indicate significant differences by the least significant difference (LSD) test at $P < 0.05$. ns, non-significant.

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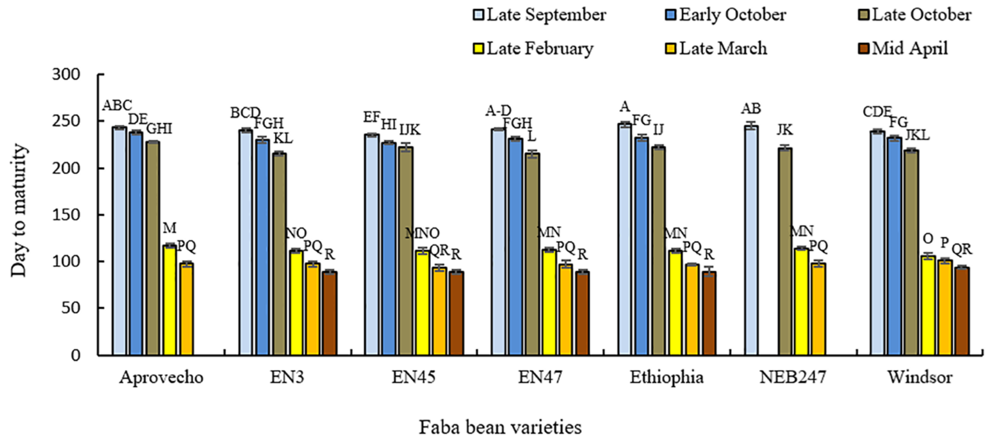

FIGURE 2
The interaction effects of varieties and three spring planting dates (late February, late March, and mid-April) and three fall planting dates (late September, early October, and late October) on the day to maturity for faba beans. Different letters indicate significant differences by the least significant difference (LSD) test at $P < 0.05$. Bars on the columns are means ± standard error.

interactions ($P > 0.05$) (Table 3). Windsor had the highest number of seeds per pod (3.03), with no significant difference between the other varieties. Across all varieties, the highest number of seeds per pod was recorded for faba beans planted in late October (2.64), which did not significantly differ from those planted in early October (2.45) (Table 3).

3.8 Number of seeds per plant

The number of seeds per plant was significantly influenced by both variety and planting dates ($P< 0.01$), with no significant interactions (Table 3). Among the varieties, EN3 recorded the highest number of seeds per plant (29.4), followed by Windsor (20.3); whereas Aprovecho exhibited the lowest (10.2). Faba beans planted in late September had the highest seed number per plant (26.3), which was not significantly different from those planted in early October (20.5). Conversely, the lowest seed number per plant was observed in spring plantings, particularly in mid-April (11.4) (Table 3).

3.9 100-Seed weight

The 100-seed weight was significantly influenced by both variety ($P< 0.01$) and planting date ($P< 0.05$), with no significant interaction effects (Table 3). Among the varieties, Windsor had the highest 100-seed weight (93.5 g), followed by EN47 (73.6 g), while EN45 had the lowest (27.1 g). Across all varieties, the highest 100-seed weight was recorded for faba beans planted in late October (76 g), which was not significantly different from those planted in early October (73.7 g) (Table 3).

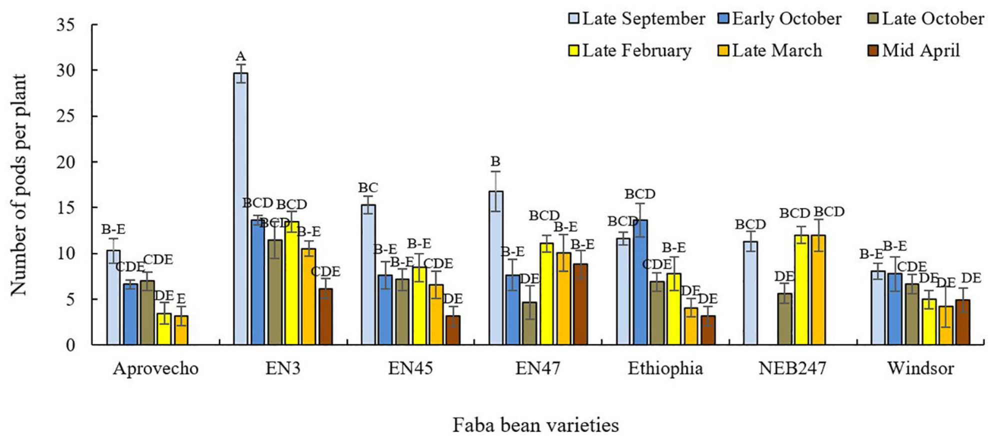

FIGURE 3
The interaction effects of varieties and three spring planting dates (late February, late March, and mid-April) and three fall planting dates (late September, early October, and late October) on the number of pods per plant for faba beans. Different letters indicate significant differences by the least significant difference (LSD) test at $P < 0.05$. Bars on the columns are means ± standard error.

3.10 Yield per plant

According to the ANOVA (Table 3), the yield of faba beans was significantly affected by variety ($P< 0.01$) and planting date ($P< 0.05$), but their interactions were not significant. Regardless of planting date, Windsor had the highest grain yield (18.7 g) compared to other varieties, while EN45 had the lowest yield (4.37 g). Across all varieties, the three fall planting dates resulted in the highest faba bean yields, which were approximately 100% higher on average than those planted in spring. There was no statistical difference between spring planting dates in terms of faba bean yield.

3.11 Yield per pod

Table 3 illustrates that variety has a significant effect ($P< 0.01$) on faba bean yield per pod; however, there was no significant effect of planting date or their interactions. The results showed that Windsor (2.89 g) had the highest yield per pod among the tested faba bean varieties, while EN45 (0.54 g) had the lowest yield per pod. The data indicated that faba beans planted in the fall had a slightly higher yield per pod compared to those planted in the spring, but this difference was not statistically significant (Table 3).

3.12 Harvest index

According to the ANOVA Table (3), the harvest index was significantly affected by both variety and planting dates ($P< 0.01$), as well as their interactions ($P< 0.05$). EN47 had the highest harvest index (52.2%), which was not significantly different from that of EN3 (51.1%), EN45 (48.9%), and Windsor (46.5%). The lowest harvest index was recorded for the variety Aprovecho, with a value of 30.5%. Across all varieties, the harvest index was highest for faba beans planted in late February (50.8%), early October (49.6%), and late October (50.6%) (Table 3). The bar chart illustrates the interactions among seven faba bean varieties across six planting dates with respect to the harvest index (Figure 4). EN47 planted in late October (61.1%) and EN45 planted in late February (60.9%) achieved the highest harvest index. Conversely, NEB247 and Aprovecho planted in late September had the lowest harvest index, which was around 10% (Figure 4).

4 Discussion

This scatter plot illustrates the relationship between yield per plant (g) and various yield components of faba beans (Figure 5). There is a positive correlation between yield and components such as pod weight per plant ($r = 0.98$, $P< 0.01$), number of pods per plant ($r = 0.40$, $P< 0.01$), number of seeds per pod ($r = 0.55$, $P< 0.01$), number of seeds per plant ($r = 0.65$, $P< 0.01$), harvest index ($r = 0.49$, $P< 0.01$), 100-seed weight ($r = 0.56$, $P< 0.01$), and yield per pod ($r = 0.66$, $P< 0.01$). The red dotted trend line suggests a linear relationship between yield and components like pod weight, number of pods per plant, number of seeds per pod, and yield per pod, supporting findings by Alan and Geren (2007) and Aziz et al. (2013) that these components often exhibit linear relationships with yield. However, the relationship between yield and the number of seeds per plant, harvest index, and 100-seed weight were non-linear. Among the yield components, pod weight per plant shows the strongest correlation with yield. Studies have shown that pod weight per plant is a significant determinant of overall yield in faba beans, indicating a strong positive correlation (Ulukan et al., 2003; Sindhu et al., 1985; Berhe et al., 1998).

The study provides detailed insights into how variety and planting date affects various agronomic traits of faba beans, such as plant height, shoot dry weight, days to maturity, number of branches

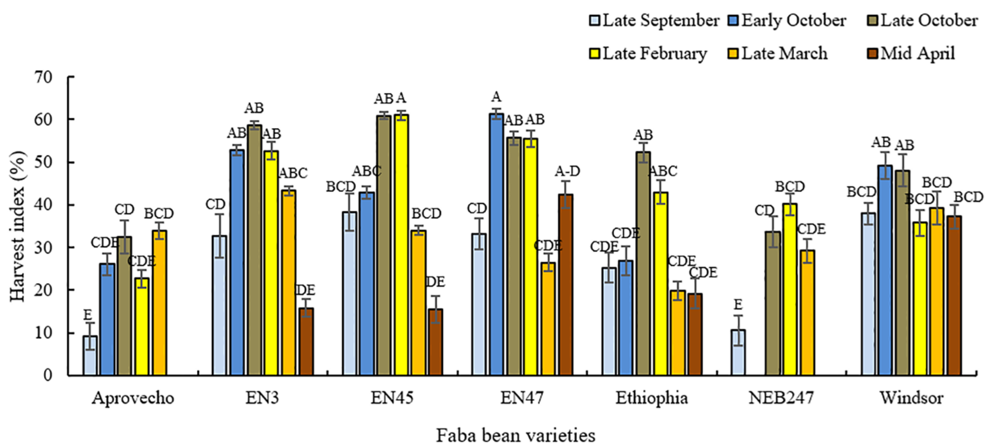

FIGURE 4
The interaction effects of varieties and three spring planting dates (late February, late March, and mid-April) and three fall planting dates (late September, early October, and late October) on the number of pods per plant for faba beans. Different letters indicate significant differences by the least significant difference (LSD) test at $P < 0.05$. Bars on the columns are means ± standard error.

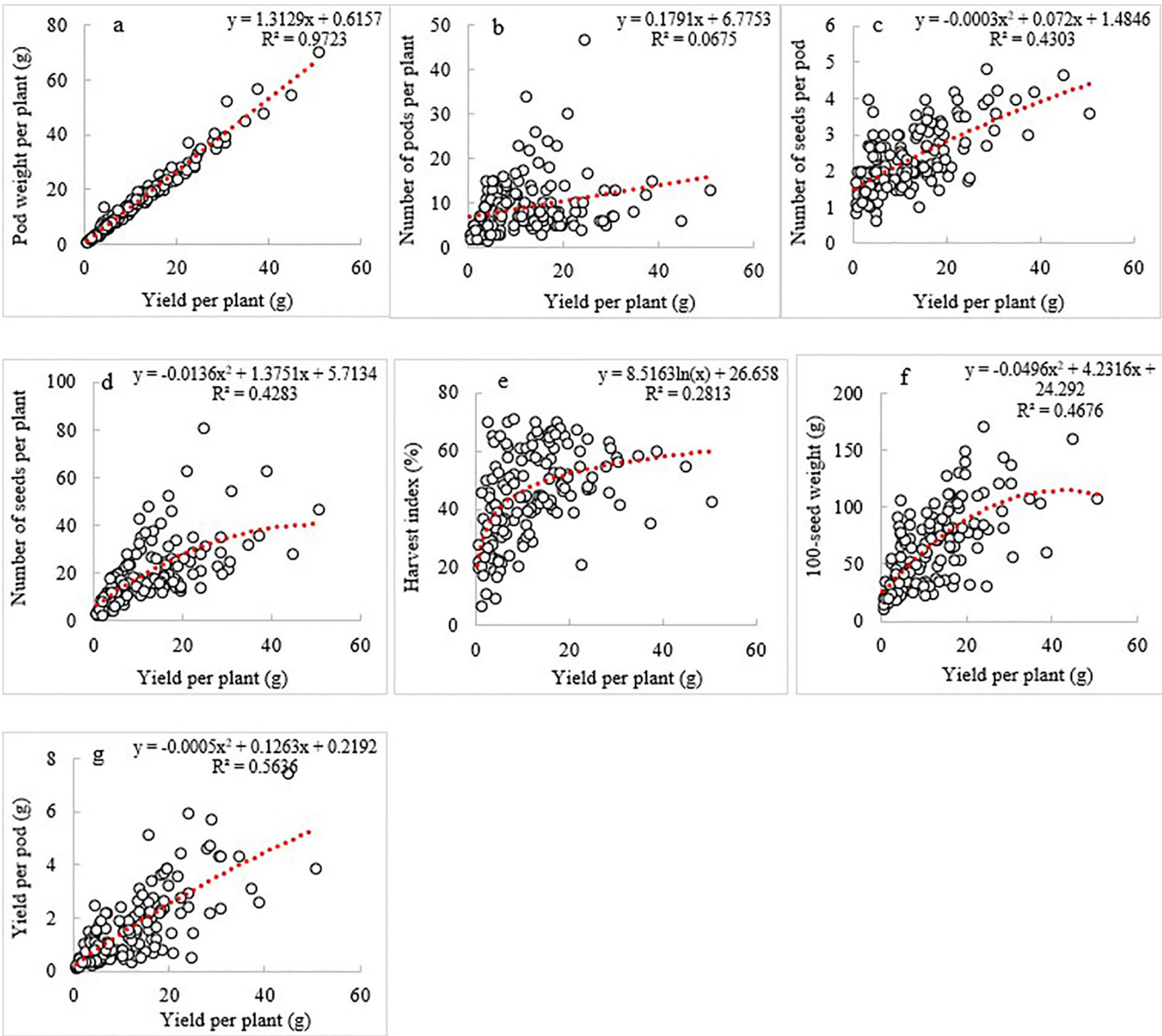

FIGURE 5
The scatter plots for faba bean yield in relationship with pod weight per plant **(A)**, number of pods per plant **(B)**, number of seeds per pod **(C)**, number of seeds per plant **(D)**, harvest index **(E)**, 100-seed weight **(F)**, and yield per pod **(G)**.

per plant, number of pods per plant, pod weight per plant, number of seeds per pod, number of seeds per plant, 100-seed weight, yield per plant, yield per pod, and harvest index. Among the varieties, Windsor demonstrated superior performance in several key areas. It achieved the highest plant height (54.5 cm), shoot dry matter (40 g), number of branches (3.54), pod weight (25.4 g), number of seeds per pod (3.03), 100-seed weight (93.5 g), grain yield (18.7 g), and yield per pod (2.89 g). Additionally, Windsor had the shortest maturity time compared to other varieties. These characteristics make Windsor an excellent choice for maximizing yield and efficiency. Following Windsor, EN47 showed commendable performance with the highest harvest index (52.2%). Given the strong correlation between pod weight, 100-seed weight, and grain yield, both Windsor and EN47 emerged as superior varieties compared to others. This correlation highlights the importance of these traits in determining overall yield performance (Duc, 1997). In contrast, EN45 exhibited the lowest values in several critical areas, including plant height, shoot dry weight, pod weight, 100-seed weight, and grain yield. These deficiencies suggest that EN45 is not well-suited for the conditions of this study. Similarly, the varieties Aprovecho and NEB247 showed specific sensitivities to planting dates. Aprovecho, when planted in mid-April, and NEB247, when planted in early October, both failed to thrive, indicating a sensitivity to hot and cold weather, respectively. This sensitivity makes these varieties less suitable for regions with extreme temperature variations. Aprovecho had the lowest number of pods per plant and the lowest harvest index (30.5%), and it also had the longest maturity time compared to other varieties. These factors further support the conclusion that Aprovecho is not an ideal variety for the region under the conditions tested. The results indicated that the choice of variety significantly impacts the agronomic performance of faba beans. These findings are consistent with previous research, emphasizing the critical role of variety selection in optimizing crop performance (Jensen et al., 2010; Siddiqui et al., 2015; Afzal et al., 2022).

Across all varieties, the planting date significantly influenced the yield and yield components of faba beans (Table 3). Faba beans planted in late September exhibited the tallest plants, longest maturity times, more branches, highest shoot dry matter, most pods per plant, heaviest pod weight, and greatest number of seeds per plant compared to other planting dates (Table 3). Previous studies support our findings, indicating that optimal planting times can significantly influence vegetative growth and plant height (Wakweya et al., 2016; Refay, 2001; Turk and Tawaha, 2002). The extended growing period afforded by fall planting dates likely contributes to the longer maturity times observed (Ellis et al., 1992). Our results demonstrated that the shoot dry matter of faba beans planted in the fall was nearly 100% higher than those planted in the spring. This finding is consistent with Thalji and Shalaldeh (2006), who reported a significant yield advantage (157%) and increased shoot and root growth with early planting (end of November). We observed that faba beans planted in fall had 58% more branches compared to those planted in spring. As shown in Table 3, pod development for faba beans was higher for those planted in fall compared to spring, which aligns with previous studies indicating that fall planting dates result in greater pod development and weight (Jensen et al., 2010). This pattern suggests that fall planting dates provide favorable conditions for pod formation, supported by research from Loss and Siddique (1997). El-Metwally et al. (2013) found that sowing on October 25th produced the highest growth characteristics and pigment content (total chlorophyll), while the greatest yield and its components were achieved with the November 25th sowing date. The 100-seed weight of faba beans planted in the fall was approximately 34% higher than those planted in spring. Previous research has shown that environmental conditions during fall planting favor the development of larger seeds (Duc, 1997). The data showed that faba beans planted in the fall had a slightly higher yield per pod than those planted in the spring, although this difference was not statistically significant (Table 3). The three fall planting dates produced the highest faba bean yields and had a higher harvest index, averaging about 100% and 8% more than those planted in spring, respectively. This trend suggests that fall planting dates enhance seed production, consistent with findings by Khan et al. (2010). In the current study, some varieties (Ethiopia, NEB247, and Aprovecho) planted in late September entered the reproductive phase before winter. Being indeterminate, they continued to bloom even after losing their flowers in December and January. It is necessary to use indeterminate varieties for fall planting because if the weather conditions are favorable and encourage blooming, the plants are unlikely to retain their flowers through the winter. Other varieties planted in the fall in this study remained in the growth stage and did not enter the reproductive stage before spring. The biggest challenges for spring planting include cold weather at the beginning of the season and rain, which prevent the soil from being ready for planting. Additionally, hot weather during the flowering stage of faba beans can hinder grain production. As the weather warms, disease problems such as chocolate spot and rust will spread more rapidly, favoring warmer temperatures of 15–25°C and above 20 C°, respectively (Stoddard et al., 2010). Therefore, for spring planting, faba beans should be planted as soon as possible to avoid hot weather during the flowering stage.

5 Conclusion

The study demonstrates that both variety and planting date play critical roles in determining the agronomic performance of faba beans. Varieties like Windsor and EN47, which exhibit superior traits across multiple categories, are preferable for achieving high yields. Conversely, varieties such as EN45, Aprovecho, and NEB247, which show poor performance or sensitivity to adverse conditions, are less suitable. Fall planting dates generally result in superior growth, yield, and maturity characteristics, highlighting their importance for maximizing faba bean production. To maximize the agronomic performance and yield of faba beans, careful consideration must be given to both variety selection and planting date. However, given that this study was conducted in a single region and soil type, future research should extend these investigations to diverse environmental conditions to validate and generalize the findings. Additionally, further studies are needed to clarify the physiological relationship between photosynthesis rates and the sink-source relationship and to explore how planting dates impact the nutrient components of faba beans, such as amino acids, fat, and carbohydrates.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

ST: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. HZ: Writing – review & editing. SF: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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