





ORIGINAL ARTICLE

Quantifying plant biomass and seed production in camelina (*Camelina sativa* (L.) Crantz) across a large range of plant densities: Modelling approaches

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Abstract

To date, there has been little agreement on supporting the hypothesis that how some key vegetative traits of camelina (*Camelina sativa* (L.) Crantz var. 'Soheil') are dependent on plant biomass. Therefore, the main aim of this investigation was to quantify the relationship between the size of camelina plants and seed production across a broad-range of plant densities through modelling approaches. To make a wide range of plant densities, a fan design was used in eight replicates in an experimental field at Sari Agricultural Sciences and Natural Resources University, Iran. To quantify the relation between plant density and other plant traits, a regression analysis was carried out and the coefficient of determination (R^2) was considered to evaluate the goodness of fit model. A power model ($y = ax^b$) could describe well the relationship between plant density (ranged 113–2905 plants m^{-2}) and plant biomass, seed production, number of seeds per plant, stem diameter, and siliques number, with the coefficient of determination (R^2) values of 0.85, 0.87, 0.65, 0.64, and 0.90, respectively. The harvest indexes were 13.8%–26.9%, depending on plant density. Seed production per plant was positively correlated to the siliques number ($r = 0.85$), the branch number ($r = 0.80$), and the seed number ($r = 0.99$) which could be key components of camelina seed production per plant. Furthermore, no significant correlation was found among plant height, thousand-seed weight, and harvest index with seed production per plant. In conclusion, plant biomass could be considered an important trait to predict plant growth models of camelina. Also, a lower plant density of camelina can be compensated by a greater number of siliques, branches and seeds per plant.

KEYWORDS

Camelina sativa, mathematical models, plant biomass, regression analysis, vegetative traits, yield components

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1 | INTRODUCTION

Camelina (*Camelina sativa* (L.) Crantz), belonging to the Brassicaceae family, is an ancient oilseed crop that has recently attracted considerable interest because of its several agronomic characteristics and its encouraging industrial, food, and feed applications (Waraich, Ahmad, et al., 2020; Waraich, Ahmed, et al., 2020). This plant showed a promising capability, not only because of its ability to grow in poor and marginal lands (Angelini et al., 2020), but also because of its several beneficial uses such as soil protection from erosion, weed control, and improving other crops' yield when cultivated in double or relay cropping (Berti et al., 2017). Camelina seeds gather 29%–43% oil of total seed dry matter (Rodríguez-Rodríguez et al., 2013) with about 50%–60% of polyunsaturated fatty acids characterized by 40%–45% and 15%–20% of omega-3 and omega-6 fatty acids, respectively (Ergönül & Özbek, 2018; Ibrahim & El Habbasha, 2015; Mansour et al., 2014). Camelina seeds are also rich in proteins (23%–27%), tocopherols, antioxidants, and poor anti-nutritional erucic acid and glucosinolates contents, conferring to seeds and raw oil high longevity with storage time (Eidhin et al., 2003). However, camelina productivity and quality traits depend on genetics, environmental conditions, and crop culture (Vollmann et al., 2007). Berti et al. (2011) showed that to attain an optimal plant density of 125–200 plants m^{-2} , the seed sowing rate should be around 3–7 kg per ha (approximately 250–600 seeds per m^2). Other studies report that seeding at 334 and 350 plants per m^2 was sufficient to achieve maximum seed and oil yield in camelina (Dobre et al., 2014; Gesch et al., 2017). Also, at optimal conditions, camelina could produce 900–2240 kg of seeds per hectare (Ciubota-Rosie et al., 2013).

Seed production is one of the most influential and complex traits in crops. It has been noticed that the camelina plant density has a considerable effect on plant biomass, seed yield, and yield of seed components. Crops attain maximum seed production at a given plant density (a threshold), reaching the plateau yield above which yield decreases with an increase in production costs (Gugel & Falk, 2006). However, a decrease in plant density could not allow crops to achieve the plateau yield (Hay & Walker, 1989). To date, many researchers used several mathematical models (i.e., power, exponential, segmented, etc.) for describing the effect of plant density on plant biomass (Soltani et al., 2011), allometric relationships (Zafari Ghalehrodkhani et al., 2017), extinction coefficient and radiation use efficiency (Zahed et al., 2013), biomass (Khan et al., 2020) and yield (Zahed et al., 2011). For example, Soltani et al. (2011) fitted a power model to quantify seed production of volunteer canola (*Brassica napus*) and wild mustard (*Sinapis arvensis*) as a function of their plant biomass. In general, quantification of seed production as a function of plant biomass could be considered a simple method for estimating seed production and an alternative to actually assessing seeds, which is very labour-intensive (Lutman, 2002).

There are many reports on camelina dealing with plant density (McVay & Khan, 2011), sowing date (Angelini et al., 2020; Berti et al., 2011), harvest time (Walia et al., 2018), nitrogen, sulphur, and phosphorus fertilizer (Lošák et al., 2011; Solis et al., 2013) effects on growth and yield. However, few and/or no works studied the effect of plant biomass on seed production of camelina taking into account a wide spectrum of plant densities. Thus, the main objective of the present work was to

quantify the relationship between the size of camelina plants and seed production across a broad-range of plant densities through modelling approaches.

2 | MATERIALS AND METHODS

2.1 | Site description

This study was performed at the Research Farm of Sari Agricultural Sciences and Natural Resources University, Sari, Iran, located at 36°39'39.0" Latitude N and 53°04'19.4" Longitude E, with an elevation of 30 m a.s.l. The region's climate is a temperate humid type with an annual precipitation of 789 mm and an annual mean temperature of 17.9°C. The daily mean air temperature and rainfall which was obtained from the nearest synoptic weather station during the growing season is shown in Figure 1.

2.2 | Seed collection and experimental design

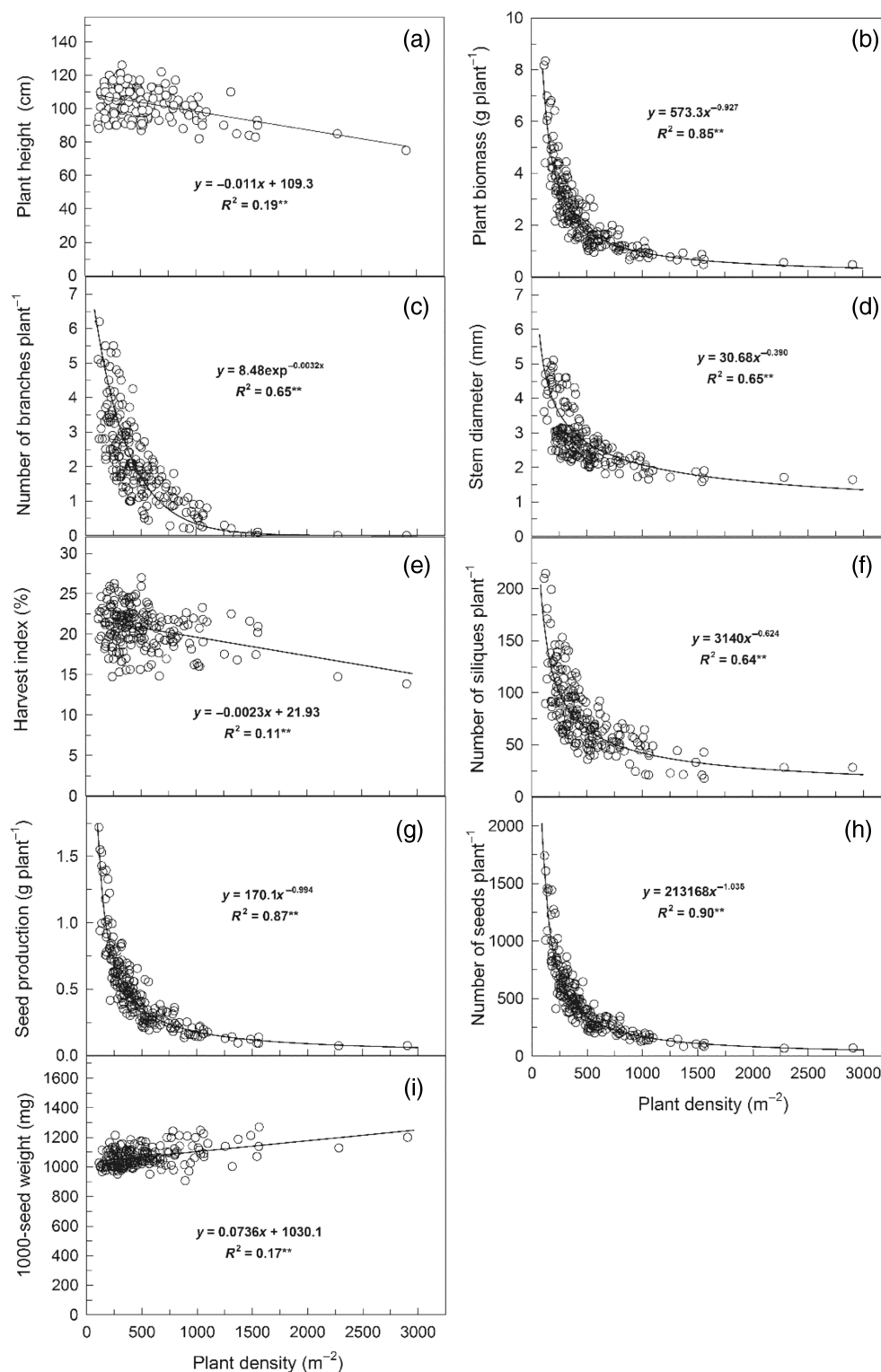
Camelina seeds var. 'Soheil', as a native winter variety (a double haploid F1 generation plant from a cross between Blaine Greek (as a paternal parent) and Calena (as a maternal parent)) were provided from Mazandaran Agricultural and Natural Resources Research and Education Center, Sari, Iran in May 2020. The viability of the seeds was more than 95% (assessed by the ISTA method) at the sowing date. To make a wide range of plant densities, a fan design suggested by Soltani et al. (2011) was used in eight replicates. In this method, each plot was 36 m^2 (6 m × 6 m) and camelina seeds were planted in 20 rows (Figure 2). Indeed, the planting started from one corner of each plot with zero inter-row spacing and the longer the rows extended on opposite sides, the more the spacing between rows widens to reach 60 cm. Seeds were sown manually on 4 December 2020 at a 2–3 cm burial depth.

The main physicochemical properties of the soil (0–30 cm) were: 1.4% soil organic carbon; pH 7.45; electrical conductivity 1.2 dS per m; total nitrogen 0.18%; 20.0 and 270 mg per kg available P and K, respectively. The soil type was also clay silt. At the sowing time, one part of urea (46% N; 50 kg per ha) and total potassium sulphate (K_2SO_4 , 50% K, and 18% S; 50 kg per ha), triple superphosphate (46% P_2O_5 ; 100 kg per ha) were applied as basal fertilization and another part of urea was used as top-dressing (120 kg per ha, beginning of the elongation stage). The experiment was carried out under optimal agronomic conditions, which means that, if necessary, weeds were controlled by hand, and Metaldehyde was used to control snails at the early stages of the growth. Plots were not irrigated because the precipitation was enough during the growing season (Figure 2).

2.3 | Measurements

At harvesting time (160 days after sowing), 0.5 m around each plot was left as wide margin, and the remaining area of each plot (25 sub-

FIGURE 1 Mean daily air temperature (open circle) and mean daily precipitation in the growing season of *Camelina*. The experiment was started on 4 December 2020 (sowing date) and ended on 20 May 2021 (harvesting date).



plots, 1 m^2) was harvested. At each sub-plot, the plants were accurately collected from the soil surface and bagged to prevent seed shedding and plant shattering. Then, all bags were transferred to the laboratory for future measurements. Actual biological yield for each sub-plot was determined by a balance with 0.01 g precision after 2 days air-drying the plant under field conditions. Thereafter, 10 plants were randomly selected from each bag and the following parameters were measured: plant height (cm), stem diameter (mm), number of

branches, siliques and seeds plant^{-1} . *Camelina* plants were counted to determine the real plant density for each sub-plot. To determine the actual grain yield, the seeds were hand shelled from the siliques and weighed by the balance after an air-drying week at room temperature. Harvest index (HI), defined as a ratio of grain yield (GY) to biomass yield (BY), was calculated using the following model $[\text{HI} \% = (\text{GY}/\text{BY}) \times 100]$. Plant biomass (dry weight (DW) in g) was calculated by dividing the whole biomass produced in each subplot by its

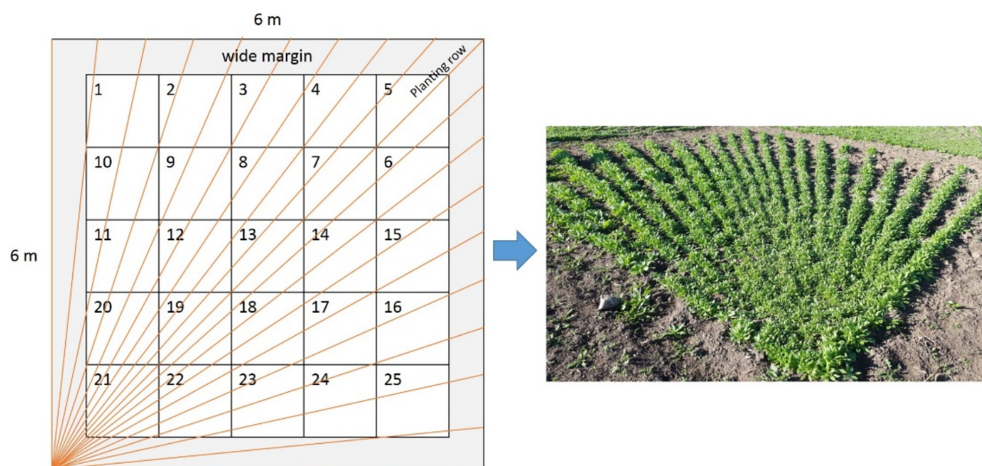


FIGURE 2 Fan design plot used for planting. There were eight plots in this experiment and each plot had 20 planting rows. Also, 0.5 m around each plot was left as wide margin, and the remaining area of each plot (25 sub-plots, 1 m²) was harvested.

corresponding plant density. The same method was used to calculate grain production (g plant⁻¹). Three replicates of 100 seeds were manually counted to determine 1000-seed weight as mg.

2.4 | Modelling

To quantify the relation between plant density and the above-mentioned traits, a regression analysis was carried out using the Statistical Analysis System (SAS) ver. 9.4 software, and the coefficient of determination (R^2) was considered to evaluate the goodness of fit model.

A power model, as described by Soltani et al. (2011), was fitted to the data of plant biomass, grain production, stem diameter, number of siliques and seeds per plant as a function of plant density. The model can be expressed as:

$$y = ax^b. \quad (1)$$

An exponential model was fitted to quantify the relationship between the numbers of branches per plant with plant density:

$$y = a \exp^{-bx}. \quad (2)$$

For quantifying the relationship between the plant height, harvest index and thousand-seed weight with plant density a simple linear model was applied:

$$y = a + bx. \quad (3)$$

In all the above models, y is the estimated traits at different camelina densities, x is plant density in m⁻², a is the intercept and b is the model parameter.

The simple linear and quadratic models were also fitted for modelling the relationship between the above-mentioned traits with plant biomass (g plant⁻¹) in camelina. Also, Pearson's pairwise comparison between studied traits was investigated in the present work.

3 | RESULTS

3.1 | Site climatic conditions

Based on the climatic conditions registered during camelina growth, the sowing in December coincided with important precipitation (73 mm), mean RH (79.9%), and average air temperature (7.9°C) (Figure 2) that would be beneficial for seed germination since the germination base temperature is 1.5°C for this species (Hosseini Sanekhoori et al., 2021). The total and mean monthly precipitation during the camelina growing period (December–May), were 245.3 and 40.9 mm, respectively, with a minimum of 7.1 mm in April 2021 and a maximum of 73.0 mm in December 2020. The mean monthly temperature registered a minimum of 7.9°C and a maximum of 20.1°C in December and May, respectively.

3.2 | Changes on growth and yield components of camelina as a function of plant density

In the present work, a fan design suggested by Soltani et al. (2011) was used to obtain a large spectrum of plant biomass as a function of different plant densities. Plant density varied from 113 to 2905, with an average of 516 plants m⁻². Similar trends were observed for plant height, plant biomass, and stem diameter. Plant height increased from 75 to 126 cm with decreasing plant density (Table 1, Figure 3a). Plant biomass ranged from 0.47 to 8.34 g DW plant⁻¹ with an average of 2.46 g DW plant⁻¹. The minimum stem diameter was 1.58 mm, and the maximum was 5.21 mm, which were recorded in high and low plant densities, respectively (Table 1, Figure 3e). Concerning the number of branches per plant, the highest value was 6 and the average was 2 (Table 1). When studying yield components, our finding indicated that the number of siliques per plant varied from 17 to 214, with an average of 78 siliques plant⁻¹. These siliques produced 107 and 1741 as minimum and maximum number of seeds per plant. In addition, the 1000-seed weight was 906.6 and 1269 mg as minimum and

TABLE 1 Mean, standard deviation (SD), minimum and maximum values of the studied traits of camelina ($n = 200$).

Traits	Mean	SD	Minimum	Maximum
Plant density (plants m^{-2})	516	365	113	2905
Plant height (cm)	103.6	9.11	75.0	126.0
Plant biomass (g plant $^{-1}$)	2.46	1.47	0.47	8.34
Seed production (g plant $^{-1}$)	0.49	0.30	0.072	1.72
Harvest index (%)	20.7	2.57	13.8	26.9
Stem diameter (mm)	2.67	0.54	1.58	5.21
Number of siliques plant $^{-1}$	78.8	35.7	17.6	214.7
Number of branches plant $^{-1}$	2.14	1.28	0.00	6.20
Number of seeds plant $^{-1}$	485.9	308.9	107.2	1741.4
1000-seed weight (mg)	1068.1	65.3	906.6	1269.3

maximum, respectively. The minimum and maximum harvest indexes were 13.8% and 26.9%, respectively, with an average of 20.7% (Table 1).

A power model (Equation 1) provides a function to describe the mathematical relationship between plant biomass, seed production, seed number, stem diameter, and siliques number with plant density (Figure 3b,c,e,f,i). Our finding indicated that the model could describe well the relationship between these traits with R^2 values of 0.85, 0.87, 0.65, 0.64, and 0.90, respectively. Also, the number of branches was highly correlated to plant density ($R^2 = 0.64$), as described by the exponential model (Figure 3g). However, plant height and harvest index were poorly correlated to the plant density fixed by the linear model (i.e., $R^2 = 0.19$ and 0.11, respectively) (Figure 3a,d). Contrarily, 1000-seed weight somewhat increased linearly with the increase of plant density ($R^2 = 0.17$) (Figure 3h).

3.3 | Changes on growth and yield components of camelina as a function of plant biomass

In a further step, the effects of plant biomass on the above-mentioned parameters were analysed using different models (Figure 4). Based on the model estimation, the maximum plant height (i.e., 110 cm) was observed when plant biomass was 4.5 g DW plant $^{-1}$, nonlinearly decreasing ($R^2 = 0.27$) at higher and lower plant biomass (Figure 4a). A quadratic regression model indicated also that there was a significant relation between the stem diameter and the number of branches with plant biomass ($R^2 = 0.60$ and 0.66, respectively) (Figure 4d,f). Indeed, stem diameter and the branch number per plant gradually increased with increasing plant biomass (i.e., decreasing plant density) until 6 g DW plant $^{-1}$, then approximately remaining constant (3.5 mm for stem diameter and 4.5 for branches per plant, as average).

Other parameters (i.e. the number of siliques per plant, seed production and the number of seeds per plant) linearly increased with plant biomass, showing high accuracy (R^2 values of 0.71, 0.95, and 0.94, respectively) (Figure 4e,f, and g). Indeed, the plant biomass of 1, 5, and 8 g plant $^{-1}$ resulted in 0.2, 1.0, and 1.6 g of seeds plant $^{-1}$, respectively (Figure 4b). Similarly, the number of siliques plant $^{-1}$ were 49, 131, and 192, respectively for the same plant biomasses (1, 5 and 8 g) (Figure 4e). The same plant biomass (i.e., 1, 5, and 8 g plant $^{-1}$) produced 199, 995, and 1592 seeds plant $^{-1}$, respectively (Figure 4h). However,

there was no significant relationship between harvest index and 1000-seed weight with plant biomass ($R^2 < 0.09$), which means that the harvest index and 1000-seed weight were almost constant, namely 20.7% and 1068 mg, respectively, as an average of all plant biomass or densities (Figure 4c,g).

3.4 | Correlation analysis

A positive correlation was found between seed production per plant and number of seeds per plant ($r = 0.99$), plant biomass ($r = 0.97$), number of siliques ($r = 0.85$), number of branches ($r = 0.80$), and stem diameter ($r = 0.73$) (Figure 5). Results also showed a correlation between seed number per plant and plant biomass, number of siliques, and number of branches (Figure 5). However, plant density was significantly and negatively correlated to plant height ($r = -0.437$), plant biomass ($r = -0.656$), seed production ($r = -0.656$), harvest index ($r = -0.327$), stem diameter ($r = -0.691$), siliques number ($r = -0.621$), branch number ($r = -0.686$), and seed number per plant ($r = -0.667$). Unusually, 1000-seed weight showed a significant and positive correlation with plant density ($r = 0.41$). Thus, the number of siliques, number of branches, and number of seeds per plant could be stated as key components of seed production per plant. Conversely, plant height, 1000-seed weight, and harvest index showed no high correlation ($r < 0.34$) with seed production per plant (Figure 5). Besides, not significant correlation was registered between seed yield (g m^{-2}) and all studied traits (data not shown).

4 | DISCUSSION

Plant biomass, seed production, number of seeds, stem diameter, and number of siliques were strongly affected by plant density (plants per m^2). Similarly, other results on camelina (Bobrecka-Jamro, 2017) and rape (Leach et al., 1999) showed that higher density plants brought fewer branches and consequently fewer siliques per plant. In the same way, other findings on camelina and canola (Mobasser et al., 2008; Soltani et al., 2011; Yantai et al., 2016) specified that high plant density produces fewer numbers of branches and pods and reduced seed production per plant compared to those cultivated under low

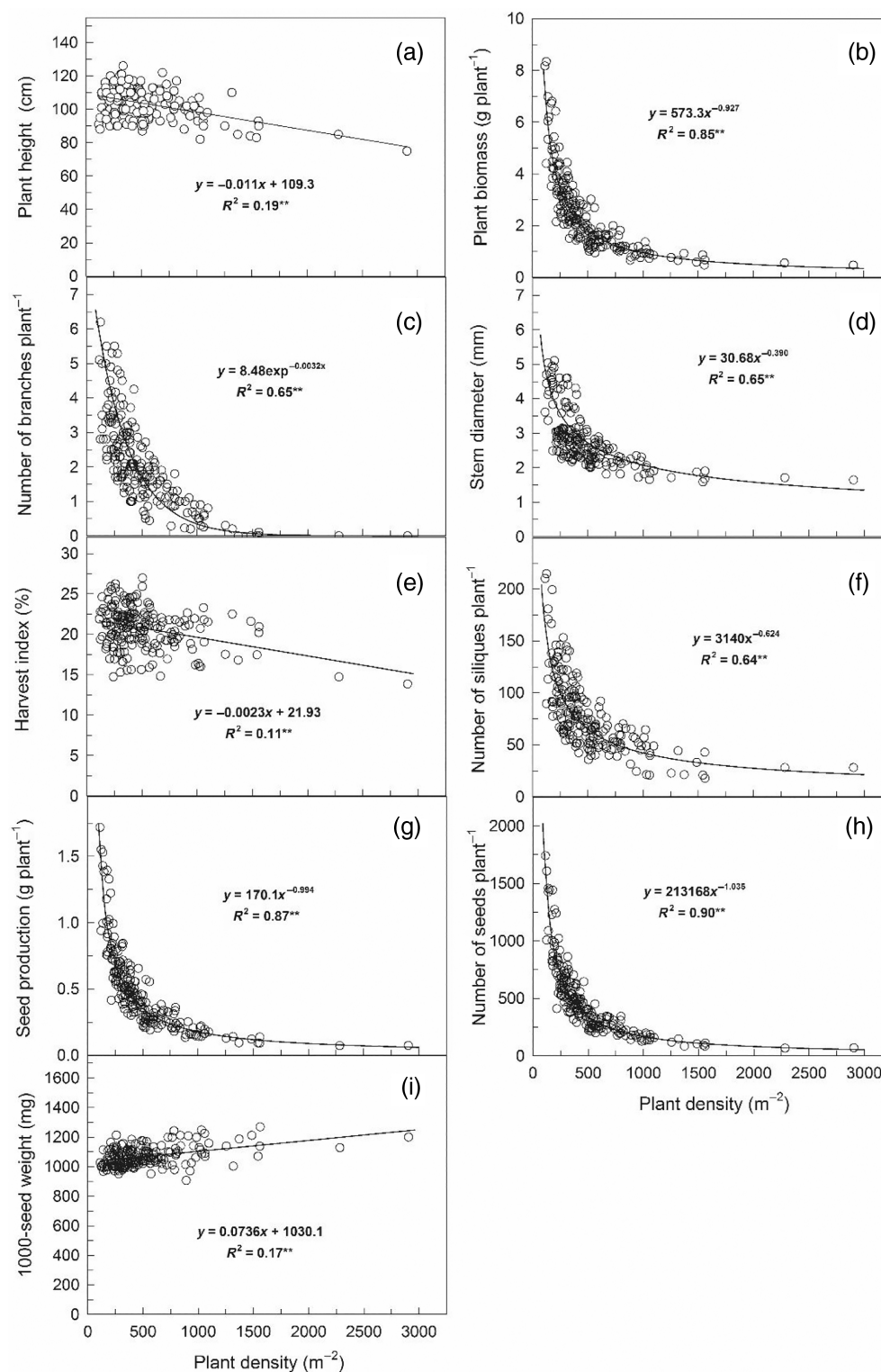
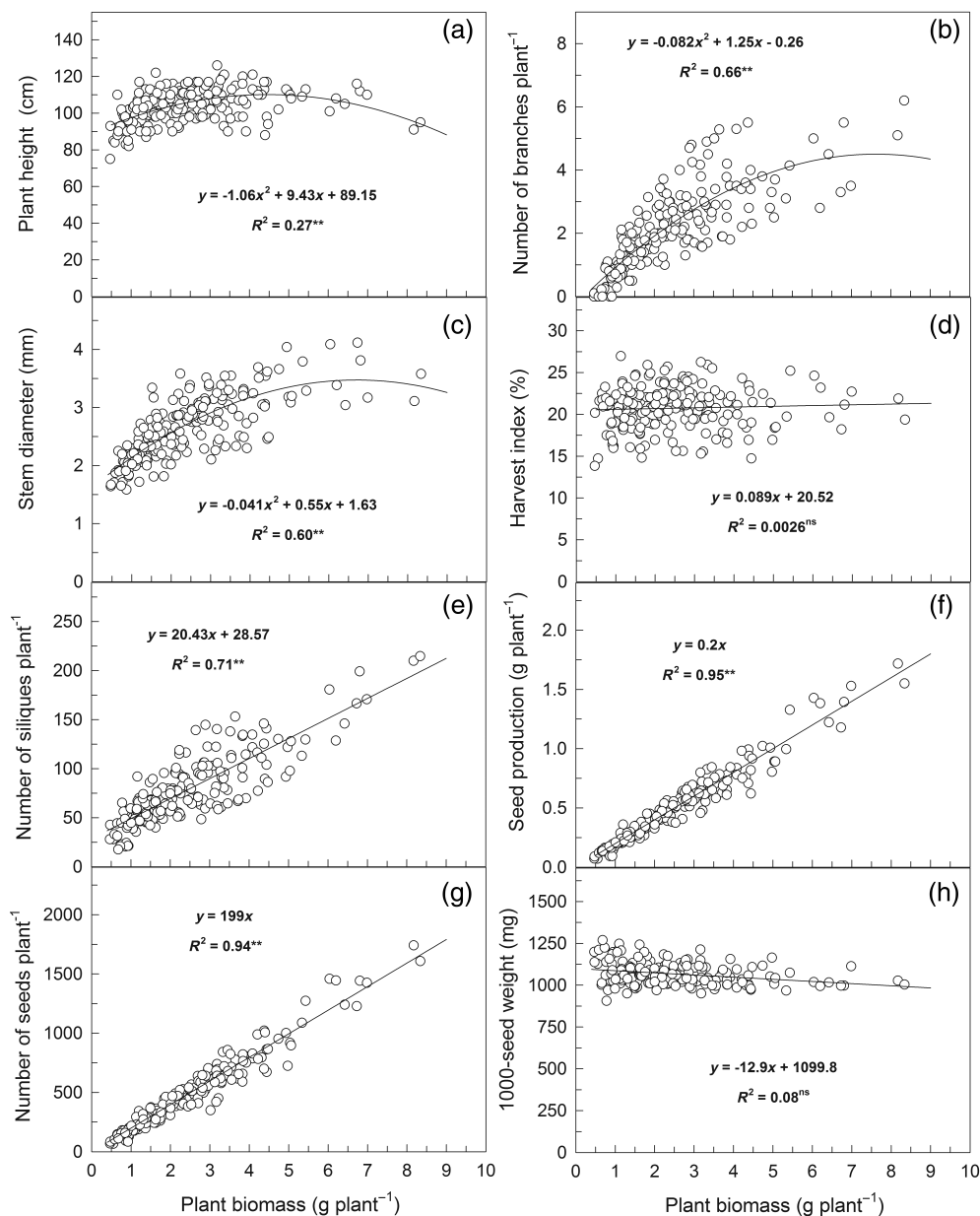


FIGURE 3 Plant height (a), plant biomass (b), number of branches plant^{-1} (c), stem diameter (d), harvest index (e), number of siliques plant^{-1} (f), seed production (g), number of seeds plant^{-1} (h) and 1000-seed weight (i) as a function of plant density (plants m^{-2}) in camelina ($n = 200$). **: Significant at $P < 0.01$ level.

densities. This finding is consistent with the results of Codina-Pascual et al. (2022) who reported a significant reduction in the seed production and number of seeds per plant in two different varieties of camelina when the higher densities resulted in competition between them. These results are also similar to those of López-Bellido et al. (2000) on *Lupinus albus*, who showed that fewer pods resulted from the decreased number of branching at higher plant densities. This

phenomenon was also related, for winter and spring rapeseed (Kuai et al., 2015; Rondonini et al., 2017) and canola (Angadi et al., 2003), to their adaptive plasticity to preserve their productivity, being the lower plant density compensated by more branches production. Walia et al. (2018), by reporting the higher plant height, number of branches, number of pods, 1000-seed weight, and seed yield in lower-density of camelina plants, found a link between these parameters and some

FIGURE 4 Plant height (a), number of branches plant⁻¹ (b), stem diameter (c), harvest index (d), number of siliques plant⁻¹ (e), seed production (f), number of seeds plant⁻¹ (g) and 1000-seed weight (h) as a function of plant biomass (g plant⁻¹) in camelina ($n = 200$). **: Significant at $P < 0.01$ level.



photosynthetic efficiency-related parameters such as leaf area index, leaf area duration, and net assimilation rate. Plants progressively accumulate more biomass and produce more leaves to keep on for a long time (Angelini et al., 2020; Hossain et al., 2019). However, the biomass decrease at higher plant density is accredited to the competition between populations, which most likely affected negatively plant height (Soltani et al., 2011).

Results showed low correlation of harvest index, plant height, and 1000-seed weight with plant density. Harvest index and plant height somehow decreased with plant density. This is consistent with the results on white lupin (*L. albus* L.) (López-Bellido et al., 2000), on winter oilseed rape (*B. napus* L.) (Kuai et al., 2015; Soltani et al., 2011), and on camelina (*C. sativa* L.) Crantz (Angelini et al., 2020; Waraich, Ahmad, et al., 2020; Waraich, Ahmed, et al., 2020). Indeed, the reduction of plant height is probably because of plant competition for water as the field was rain-fed without any irrigation. Moreover, the

decreased plant height of camelina under higher plant density might be because of lowered numbers of branches and siliques, which improved light quality and decreased shading; consequently, plants do not develop longer stem internodes. However, 1000-seed weight slightly increased because the camelina probably compensated for a loss in number of siliques and seeds per plant with higher seed weight. This finding corroborates the ideas of Leishman (2001), who proposed a negative correlation between seed size/weight and seed number across a range of plant species from a range of habitats. Lázaro and Larrinaga (2018) have speculated that such a negative relationship between seed weight and number can be associated with resources allocation patterns within the plant in different fruit and reproductive organs organization structures. Similarly, Leach et al. (1999) reported that *B. napus* L. 1000-seed weight increased with an increase in plant density. Contrarily, Soltani et al. (2011) and Kuai et al. (2015) showed that the 1000-seed weight of *B. napus* decreased with increasing plant

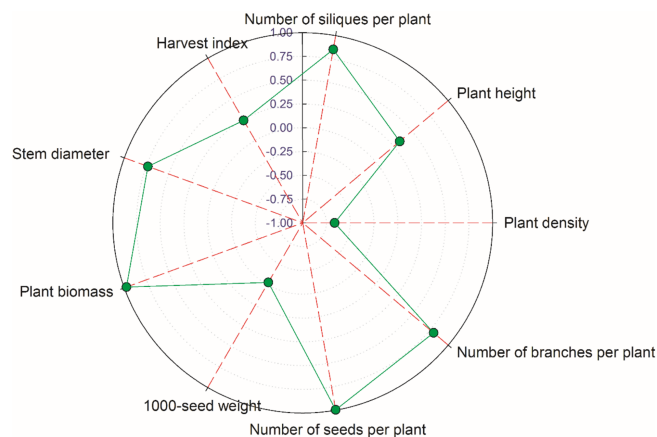


FIGURE 5 Pearson's pair-wise correlation coefficients between camelina seed production and the other variables considered in this study ($n = 200$). All relationships are significant at 0.01 probability level.

density, although no statistically relevant correlation was found. Li et al. (2019), on sunflower, and Waraich, Ahmad, et al. (2020) and Waraich, Ahmed, et al. (2020), on camelina, suggested that the decrease in 1000-seed weight is probably because of the intraspecific competition.

The findings are in accordance with El Naim and Jabereldar (2010), who showed that high plant densities decreased the harvest index and number of pods per plant of cowpea (*Vigna unguiculata* L.). Indeed, low-density plants have more opportunity to take in a greater quantity of resources like water and nutrients (Jamont et al., 2013) and light (Sunil et al., 2013) than high-density ones.

To determine the optimum plant density, many factors should be considered such as crop type, edaphic and climatic conditions and so forth (Gan et al., 2015). Deng et al. (2012) and Gan et al. (2015) stated that the optimum plant density could be determined by modelling the estimated maximum plant biomass. However, many recent works suggested that seed production is allied to plant biomass rather than plant density (Franke et al., 2007; Soltani et al., 2011). Bennett et al. (2017) used linear regression to study the relationship between seed yield and phenotypic traits within 37 lines of *B. napus*. Similarly, a linear regression described well the relationship between seed production and biomass of velvetleaf (Nurse & DiTommaso, 2005). Likewise, Angelini et al. (2020) used generalized linear models for the number of siliques per plant, number of seeds per silique, and plant density. The same method was used in this study to quantify the effect of plant biomass on number of siliques, number of seeds, and the seed production. The findings are harmonized with those of Soltani et al. (2011) who showed that there is a satisfactory link between plant biomass and seed production in both species *B. napus* and *S. arvensis*. Ollerton and Lack (1998) showed also that plant biomass was the most crucial trait on the reproductive success of *Lotus corniculatus*.

The results showed that the number of seeds per plant, number of branches, stem diameter, and number of siliques, were significantly correlated with seed production per plant, showing that these traits are the key yield components linked to camelina production per plant.

These findings agree with the results of Bennett et al. (2017) who showed that the number of seeds per plant and pods per plant were highly correlated with seed production per plant.

Recently, Rastegar et al. (2018) showed that the stem diameter has a significant role in the storage of assimilates during the growing period and that the possibility of transfer of these assimilates plays a significant role in filling of grains; the higher the diameter of the stem, the higher optimum production potential of the plant is. Actually, an increase in the stem diameter leads to a better distribution of the leaves on the stem with a good distribution of radiation more favourably in the plant population, and consequently, improving assimilates accumulation and transfer (Rastegar et al., 2018). However, earlier traits used as essential yield components for seed production per plants such as pod length (Zhang et al., 2010), seed weight per pod (Yang et al., 2012), number of seeds per pod (Chay & Thurling, 1989), and 1000-seed weight were not significantly correlated with seed yield per plant of *B. napus* (Bennett et al., 2017). It is noteworthy that the studied traits (i.e., number of seeds, branches, and siliques per plant, and 1000-seed weight) were not correlated to seed yield (g m^{-2}) of camelina (Table S1), similarly to previous results on *B. napus* (Tsialtas et al., 2017). Contrarily, the results of Berti et al. (2011) on camelina indicated that the siliques number per plant and 1000-seed weight are the leading yield components related positively with seed yield of camelina. The present work showed no correlation between seed yield and plant height as reported by Tsialtas et al. (2017). The reason of obtaining this result is not clear but it may have something to do with the plasticity of the yield parameter in the camelina, as previously proposed by Urbaniak et al. (2008), McVay and Khan (2011), and Gesch et al. (2018), who repeatedly reported that the seed yield (g m^{-2}) is little affected over a large range of plant densities because of its yield plasticity.

5 | CONCLUSIONS

The number of siliques per plant was negatively correlated with plant density. Therefore, a lower plant density of camelina can be compensated by a greater number of siliques per plant. This trait is known to grow up at low plant density with regard to camelina adaptive plasticity to bear cultivation. More branching is also produced to compensate for lower plant density. This was further corroborated by the absence of a clear relationship between camelina yield and the number of plants per unit area. Moreover, seed production as an essential trait was significantly and positively correlated to the number of seeds per plant, the number of branches, stem diameter, and the number of siliques, which was also significantly and positively correlated to plant biomass. Consequently, plant biomass could be considered an important trait to predict plant growth models. Besides, these results open new horizons on the physiological and agronomic response of camelina to the plant density and the plant biomass, taking into account its photosynthetic behaviour and other parameters such as leaf area index and light perception. However, more research on this topic needs to be undertaken before the association between plant density

and agronomic parameters is more clearly understood, especially by investigating plant responses to environmental stress.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support this study will be shared upon reasonable request to the corresponding author.

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