

Morphological plasticity of *Abutilon theophrasti* (Malvaceae) reveals its variable growth strategies in dealing with complex biotic environmental factors

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Article

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Abstract

Increased density and delayed emergence are two major biotic factors in nature that have profound and complex effects on plants. No studies have attempted to compare the responses of plants to the two factors via morphological plasticity, particularly in dynamic patterns. We subjected plants of *Abutilon theophrasti* to four emergence times and three planting densities and measured and analyzed a number of mass and morphological traits at different growth stages. Across both stages, plants emerged in late spring had the highest total mass, and spring and late-spring plants had higher stem mass allocation than later germinants, but plants with delayed emergence had higher leaf and reproductive mass allocation, more leaves and less lateral roots, but lower stem length, stem and root diameter than early-emerged plants. Plants at high density had lower in total mass and most other traits, but higher stem allocation and length, with shorter petioles and lateral roots, than at lower densities. Results suggested plants in a dense population will prefer stem elongation to leaf/root growth, and even at the cost of reproduction, to ensure the survival of the present generations, while those emerged late will prefer leaf and reproductive growth to stem/root growth, for the persistence of future generations. The contrasting strategies revealed that plants are able to analyze the risk levels of environmental signals in an integrative way and adjust their growth strategy dependently, for better adaptation in both the recent and distant future.

Introduction

Plants are able to deal with environmental heterogeneity in many abiotic and biotic factors such as temperature, light, water, nutrients, competition and herbivory through phenotypic plasticity (the ability to produce different phenotypes in different environmental conditions) in a number of morphological and physiological traits^{1,2}. In natural world, population density and emergence timing are two major biotic factors leading to variations in plant size³, and they may have complex effects on plants^{4,5}. An increase of density can result in variations in multiple resources and interactions among plants⁶, while a delay of emergence may expose plants to different environmental cues or growing conditions, such as day length, temperature, water availability, and interactions with other individuals and species⁷⁻⁹. Therefore, initially high density and short delays in emergence can be magnified into large differences in final biomass and reproduction¹⁰⁻¹⁶.

There have been a number of studies that focus on the growth strategies of plants in dealing with increased density or delayed emergence¹⁶⁻¹⁹, and we also witness the efforts of addressing plastic responses to the two factors simultaneously in a single study^{3,20}. The two biotic factors are supposed to influence plant growth and reproduction in fundamentally different ways. For example, increased density can induce extra stem elongation while having complex effects on other traits, with the overall results of trait response depending on the strength of competition in different contexts^{4,5}. On the other hand, delayed emergence mainly leads to compressed vegetative growth and earlier reproduction at smaller plant sizes, due to shortened life cycles, than early-emerging ones¹⁸. In other words, it appears that

plants tend to respond to variations in the two biotic factors with contrary strategies, the reasons for which being not well understood. In spite of this, however, no studies to our knowledge have compared the growth strategies of plants in dealing with increased density and delayed emergence, which have been addressed irrespectively in different studies or as concrete evidence for plasticity in the same studies^{3,20}. One explanation for this problem might be that effects of these biotic factors and plant responses are often complicated in nature, leading to multiple responsive trends in each of enormous modular traits of different levels^{16,21,22}. Our understanding on plant responses to density or emergence is still very limited, let alone investigating these responses in comparison. In this study, we attempt to use the approach of principle component analysis to evaluate plant responses in a number of allocation and morphological traits, reducing the complicity and difficulty of exploring this problem, for a comprehensive understanding on how plasticity contribute to plant strategies in dealing with variations in population density and emergence time in comparison^{8,18}.

Another important aspect should be the effects of plant ontogeny. Most studies on effects of emergence timing have compared plant performance from different emergence treatments at the final growth stage, when plants of different emergence times have grown for different periods or days^{3,18,23}. Plants with delayed emergence have used shorter growth periods to reach the performance in traits of the same level as or lower than those with no delay in emergence. Comparative studies based on the final harvest may simply find the passive effects of delayed emergence, neglecting the active responses of plants to such effects. Therefore, it entails studies focusing on dynamic patterns of plant performance in response to emergence time, to evaluate plasticity in plants of the same growth periods (days). Likewise, studies on effects of increased density on plants also seldom focus on multiple growth stages (but see Wang et al. 2017, 2021). The patterns of plant biomass allocation vary with different stages due to allometric growth²⁴, thus plasticity in biomass allocation in response to environments should depend on specific growth stages to a large extent. Consequently, to compare plant plasticity in response to emergence timing and population density, requires studies that involve different stages of plant growth²⁵.

Here we conducted two field experiments of emergence time and population density with an annual weed species of *Abutilon theophrasti*, to investigate how plants respond to increased density and delayed emergence via plasticity in traits in a dynamic and integrated perspective. We subjected plants to four emergence (spring, late spring, summer and late summer) and three density (low, medium and high) treatments, and measured a number of allocation and morphological traits on plants at three stages, and analyzed the synthetical responses in these traits via principle component analysis when plants have grown for 50 and 70 days. We aimed to answer the following questions: 1) how do plants respond to emergence time and population density via integrated responses of allocation and morphological traits? 2) Do responses of these traits vary with different growth stages? And 3) Do these traits differ in response to increased density and delayed emergence?

Results

Responses of total mass

Emergence time, growth stage and their interaction had significant effects on total mass (Table 3). Total mass increased over time (LSD, $P < 0.05$) for all emergence treatments (ET) except for those emerged in late spring (ET2), which had no difference in total mass between the second and third samplings (Fig. 1A). ET2 plants had the greatest total mass of all at the second stage ($P < 0.001$), greater than the final total mass of ET1 plants ($P = 0.001$). The individuals emerged in late summer (ET4) had the lowest total mass (2.41 g) of all at the final harvest ($P < 0.001$), only reaching 29.8% of the final total mass of GT2 ones.

Population density, growth stage and their interaction had significant effects on total mass (Table 4). Across both stages, compared to low density, high and medium densities reduced total mass by average 58.15% and 46.95% respectively (LSD, $P < 0.001$ and $P < 0.01$; Fig. 1B).

Responses of all the other traits

After size effects were removed, emergence time, growth stage and their interaction had significant effects on most traits (Table 3; Figs. S1 and S2). Across both stages, ET2 plants higher reproductive mass and allocation, petiole angle and stem mass and allocation than ET3 and/or ET4 plants, and had higher total mass, stem length, stem and root diameter and petiole length than ET1 (Fig. 2C, D; Figs. S1 and S2).

After size effects were removed, population density, growth stage and their interaction had significant effects on most traits (Table 4; Figs. S3 and S4). At day 50, plants at high density performed lower in total mass and most other traits, but had higher stem mass ratio and stem length than others; at day 70, plants at high density had lower total mass, petiole length and lateral root length, but had higher stem length, compared to those at medium density (Fig. 3C, D; Figs. S3 and S4).

Integrated response to emergence time

The results of principle component analysis (PCA) conducted for each treatment differed from those for all treatments at either day 50 or 70 (Tables S1 and S2). For each treatment or across all treatments at either stage, the first two principle components explained above 50% of total variance.

Emergence time had significant effects on the first two components of PCA for both stages (Table 5; Fig. 2). Plants can be easily distinguished by the first two PCA components (axis 1 and axis 2) across all treatments, especially at day 50 (Table 5; Fig. 2A, B). At day 50, for the component of axis 1, plants of ET1 performed lower than all the other ones (LSD, $P < 0.001$); for the component of axis 2, plants of ET1 and ET2 performed better than those of ET3 and ET4 ($P < 0.05$; Fig. 2A). At day 70, ET2 plants performed higher than ET1 plants on axis 1 ($P = 0.022$) and higher than ET3 plants on axis 2 ($P = 0.043$; Fig. 2B).

Integrated response to population density

The results of PCAs conducted for each treatment differed from those for all treatments at either day 50 or 70 (Tables S3 and S4). For each treatment or across all treatments at either stage, the first two principle components explained above 50% of total variance.

Similar to emergence time, population density also had significant effects on the first two components of PCA for both stages (Table 5; Fig. 3). Plants can be easily distinguished by the first two PCA components (axis 1 and axis 2) across all treatments at both stages. At day 50, plants at high density performed lower on axis 1 and higher on axis 2 than at low and medium densities (LSD, $P < 0.001$; Fig. 3A). At day 70, plants at high density performed lower on axis 1 than at low and medium densities, but performed higher on axis 2 than at medium density ($P = 0.001$; Fig. 3B).

Discussion

Increased density can result in competition for resources, while delayed emergence can lead to inadequate time for growth and completing life cycle. As the deficiency in resources or space mainly influenced the qualitative (length) traits such as stem length, petiole length and lateral root length (which needs space for extension), the shortage of time primarily affected the quantitative (number) traits such as leaf number and lateral root number (that needs time to increase). For plants grown with neighbors, their growth more restricted horizontally than vertically⁵, thus petiole length and lateral root length decreased with increased density, with main root length, stem and root diameter not affected and stem length even elongated additionally for light competition. In spite of the limitation in space or resources, no response to density was found in quantitative traits such as number of leaves or number of lateral roots. The length of stem should be the most important for plants in a dense population, while leaf or root growth can be sacrificed, depending on the relative intensity of aboveground vs. belowground competition^{4,5}. When resource deficiency aggravates belowground competition, and plants cannot grow large enough to cause intense aboveground competition, root traits such as root mass allocation, root diameter and lateral root number will be more likely suppressed⁵. Conversely, when plants were large enough to cause competition for light, leaf traits such as leaf mass allocation, petiole length, leaf number and size more likely decreased⁴. Anyway, plants will prefer to elongate stem in the first place, prior to root or leaf growth, in the presence of neighbors or in a dense population, especially when they have grown large enough to cause competition.

In comparison, delayed emergence led to increased quantitative traits such as leaf number and decreased lateral root number, but did not reduce qualitative traits such as the length of main roots and lateral roots. These suggested plants had accelerated leaf growth and slowed down root growth, in face of delayed emergence and shortened lifetime^{18,26}. Meanwhile, stem mass allocation, stem length and diameter had all significantly decreased with the delay of emergence²⁶. These suggested plants that emerged late had allocate the greatest energy to leaf growth and the least to stem and root growth, in contrast with the responses of individuals to increased density or competition.

Plants grown in a dense population showed similar performance in some aspects as those emerged earlier in the life (in spring and/or late spring), such as lower total mass (due to slow growth) and leaf mass ratio, and higher stem mass allocation and stem length, compared to those at low density. In other aspects, plants in a dense population also performed like those with delayed emergence (in summer and late summer), such as decreased reproductive allocation, petiole length and lateral root length, relative to those at low density. For plants in response to emergence time, an extensive stem growth reflected sufficient time for vegetative growth, and a decrease in reproductive allocation reflected incomplete life cycle^{18,26}. By contrast, for plants in response to increased density, an extra stem elongation was needed for intense aboveground competition, while decreased reproduction was mainly the cost of extra stem elongation⁴.

These revealed different strategies of plants in dealing with increased density and delayed emergence. For plants in a crowded population, either aboveground or belowground resources or both should often be the factor that most limits plant growth^{4,5,27}. For plants emerged late, the most limited factor may become the time for completing their life cycles^{19,26,28}. In competition for light, plants may prefer to elongate stem extensively and sacrifice reproduction, to acquire enough resources for survival; when growth period is not enough, they may prefer to shorten stem growth, reproduce earlier at smaller plant sizes, for the persistence of future generations. In other words, when environmental changes such as inadequate growth time will not threaten the survival of current plants, they will give priority to the development of their offspring; when competition threatens the present generation, they must consider their own survival over anyone else.

The destination of reproduction is generating more offspring for population persistence, while additional stem growth is for survival of the present generation. Competition with neighbors may threaten the survival of the current generation, while inadequate growth time due to delayed emergence mainly threaten the future generations rather than current plants. Plants will sacrifice reproduction for survival under severe biotic stress such as competition, but prefer reproduction at the cost of vegetative growth for population persistence when biotic stress such as delayed emergence does not threaten survival. For a plant individual, growth first or reproduction first should be a question forever. Within limited growth season or resource availability, which is often a normal characteristics of nature environmental conditions, they have to constantly make choices between growing larger and reproducing more, for better adaptation in the changing world. Plants are able to analyze the type and relative levels of the importance, severity or lethality of various environmental changes in an integrative way, based on which they can make decisions on how to adjust their growth strategy for better development in both the recent and distant future.

Conclusions

Our results showed that plants adopted contrasting strategies in dealing with increased density and delayed emergence: when competition was intense or lethal, plants in a dense population preferred stem elongation to leaf or root growth and even sacrificed reproduction, to ensure survival of the current

generation; while if time is not enough for completing life cycle, plants with delayed emergence will accelerate leaf growth at the cost of stem or root elongation, to reproduce earlier. The contrasting strategies of plants in response to population density and emergence time revealed that plants are intelligent enough to analyze the risk levels of various environmental signals in an integrative way and to adjust their growth strategy of balancing survival, growth and reproduction dependently, for better adaptation in both the recent and distant future.

Materials and Methods

Study species and experimental design. *Abutilon theophrasti* Medicus (Malvaceae) is an annual semi-shrub herbaceous species, native to China and India, but now spreads worldwide. It can generally emerge between April and July in Northeast of China. It can grow rapidly to a height of 1-1.5 m, with stout stems, reach reproductive maturity within 90 days, and completes its life cycle in about five months²⁹. Its habitats are relatively rich of nutrients, such as open fields, roadsides, and gardens. The species shows substantial plasticity in multiple aspects such as allocation, morphology and architecture, in response to environments³⁰.

Two field experiments were conducted in 2007, at the Pasture Ecological Research Station of Northeast Normal University, Changling, Jilin province, China (44°45' N, 123°45' E). We collected seeds of *A. theophrasti* from the small local wild populations near the research station in late August 2006. Seeds were dry stored at -4°C till using for experiments. We tested effects of emergence timing (ET) and population density (PD) on plants in two experiments respectively. The soil conditions of experimental field in the growth season of 2007 were the same as that in former studies: aeolian sandy soil (pH = 8.3) with nutrients availability of organic C 3.1 mg kg⁻¹, available N 21.0 mg kg⁻¹, and available P 1.1 mg kg⁻¹.

For effects of emergence timing, we divided the whole plot into twelve 2 × 3 m sub-plots, which were randomly assigned with four ET treatments and three replicates per treatment. Seeds were grown at an inter-planting distance of 10 cm on June 7, June 27, July 17 and August 7, as four ET treatments of spring (ET1), late spring (ET2), summer (ET3) and late summer (ET4). The treatments accorded with the range of emergence timing of *A. theophrasti* in its nature habitats in northeast of China¹⁸. Annually, spring occurs between April and June in northeast of China. Changchun, a city in northeast of China, locates in the middle of Northeast China, where spring starts in late April, summer starts in early July, autumn in mid-August and winter in mid-October. In spite of this, the weather between April and May is often chilling, and precipitation is unpredictable. We did not make plants emerge during this period, to avoid severe stress and mortality early in the season, and instead set up early June as the date of spring emergence, and late June as that of late-spring emergence.

For effects of population density, the whole plot was divided into nine 2 × 3 m sub-plots, which were assigned with three PD treatments and three replicates per treatment randomly. We labeled the treatments as low, medium and high densities, which were created by growing plants with inter-planting

distances of 30, 20 and 10 cm, to reach the target densities of 12.8, 27.5, and 108.5 plants·m⁻² respectively. Seeds were grown at initial densities that were a little higher than the target ones on June 7, 2007, the same date of spring-emergence treatment. Most seeds emerged four to five days after planting. When almost all seedlings reached four-leaf stage, they were thinned to the target densities. Plots were hand weeded when necessary and regularly irrigated to prevent drought.

Data collection. For each ET treatment, we arranged three to four times of sampling at the stages of early vegetative (EV), vegetative (VE), late vegetative (LV) or early reproductive growth (ER), reproductive (RE) and late reproductive (LR) growth of plants respectively, which were defined according to the patterns of plant biomass allocation. Since plants from different ET treatments had different lengths of life cycles and nonsynchronous developments, the intervals between samplings differed for different treatments as well (Table 1). For individuals that emerged in spring (ET1), we sampled four times since they had a prolonged life cycle; and for those emerged in late spring (ET2), the sampling at day 30 were not available due to small plant sizes. At each stage, five to six individual plants were randomly chosen from each plot, making a maximum total of 6 replicates × 3 blocks × 4 treatments × 4 stages = 288 samplings. For each PD treatment, plants were sampled at 30, 50 and 70 days of growth, which represented vegetative stage, early reproductive stage and middle reproductive stage respectively. For each stage, we also randomly sampled five to six individual plants per replicate per density, making a maximum total of 6 replicates × 3 blocks × 3 treatments × 3 stages = 162 samplings.

For each individual plant, the following traits were measured (if applicable): main root length, diameter at the basal of the main root, length and number of lateral roots (above or equal to 1 mm in diameter along the main root), the length of stem, diameter at the base of stem, petiole length and angle, and leaf number (Table 2). Each plant individual was then separated into roots, stems, petioles, laminae, reproductive modules and branches (if there were any), oven-dried at 75°C for two days and weighed. Reproductive modules consisted of flowers and fruits produced along the main stem and branches, and branches included the stems and leaves on branches. The mass and morphological traits of branches were not included in statistical analyses, since plants of many samplings did not grow branches. Total mass and mass allocation traits were calculated.

Statistical analysis. Statistical analyses were conducted using SAS statistical software (SAS Institute 9.0 Incorporation, 2002). Traits used for analysis included allocation traits of root, stem, petiole, lamina, reproductive organs and all morphological traits (Table 2). To minimize variance heterogeneity, all data was log-transformed, except for petiole angles and branch angles (square root-transformed), before statistical analysis. For plant total mass, we applied two-way ANOVA to analyze effects of emergence time or density, growth stage and their interactions, and one-way ANOVA to analyze the effects of emergence time or density or growth stage within each or across all of the other treatments. Plant size (e. g. total mass) can have substantial effects on other traits, which may bias the environmental effects. Consequently, for all the other traits, we applied two-way ANCOVA for overall effects of emergence time or density, growth stage and their interactions, and one-way ANCOVAs for effects of emergence time or density within each or across all of stages, with total mass as a covariate. For a given trait,

the proportion explained by effects of total biomass (plant size) in variation in response to environments indicates apparent plasticity²⁹, and the variation due to environmental (ET or PD) effects after removal of size effects in the trait indicates true plasticity²⁴. Multiple comparisons used the Least Significance Difference (LSD) method in the General Linear Model (GLM) program, which also produced adjusted mean values and standard errors in one-way ANCOVA. To evaluate the plastic responses of plants in a comprehensive perspective, we also performed standard principal component analyses (PCA) on all traits for each treatment and across all treatments at two stages of day 50 and 70 for both ET and PD experiments, to find out the most contributive traits.

Declarations

Data Availability

The data is deposited at the Dryad Digital Repository: <https://doi.org/10.5061/dryad.x3ffbg7mz>

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Authors Contributions

S.W. and D.-W.Z. conceived and designed the experiment; S.W. carried out the experiments, analyzed the data, prepared the figures and tables, wrote and reviewed drafts of the paper; and S.W. and D.-W.Z. approved the final draft.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary Information is available for this paper at

Correspondence and requests for materials should be addressed to S.W.

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Tables

Table 1. The treatments of emergence time and population density arranged and the growth periods and states when individuals were sampled in this study. Plants of different emergence treatments (ET1-ET4) were in early vegetative (EV), vegetative (VE), late vegetative (LV) or early reproductive (ER), reproductive (RE) and late reproductive (LR) growth, in corresponding to different growth periods. The stages in bold

font were used in analyses for effects of emergence time or population on mass and allocation traits. The data of the first sampling for ET2 was not available (NA) and not included in the analyses.

Treatment	Abbrev.	Sowing date	Growth stage	Sampling date	Growth period (days)	Growth state	Final harvest
Emergence time							
Spring	ET1	Jun. 7	I	Jun. 27	20	EV	
			II	Jul. 27	50	LV/ER	
			III	Aug. 27	80	RE	
			IV	Sep. 27	110	LR	√
Late spring	ET2	Jun. 27	I	Jul. 27	30	EV	NA
			II	Aug. 17	50	LV/ER	
			III	Sep. 7	70	RE	
			IV	Sep. 27	90	LR	√
Summer	ET3	Jul. 17	I	Aug. 17	30	VE	
			II	Sep. 7	50	RE	
			III	Sep. 27	70	LR	√
Late summer	ET4	Aug. 7	I	Sep. 7	30	VE	
			II	Sep.17	40	LV/ER	
			III	Sep. 27	50	RE	√
Population density							
Low	L	Jun. 7	I	Jul. 7	30	EV	
			II	Jul. 27	50	LV/ER	
			III	Aug. 17	70	RE	
Medium	M	Jun. 7	I	Jul. 7	30	EV	
			II	Jul. 27	50	LV/ER	
			III	Aug. 17	70	RE	
High	H	Jun. 7	I	Jul. 7	30	EV	
			II	Jul. 27	50	LV/ER	
			III	Aug. 17	70	RE	

Table 2. Abbreviations for all traits with units used in this study.

Abbreviation	Trait	Unit
TM	Total mass	g
RMR	Root mass ratio	/
SMR	Stem mass ratio	/
PMR	Petiole mass ratio	/
LMR	Lamina/leaf mass ratio	/
REMR	Reproductive mass ratio	/
BMR	Branch mass ratio	/
RL	Root length	cm
RD	Root diameter	mm
LRL	Lateral root length	cm
LRN	Lateral root number	/
SL	Stem length	cm
SD	Stem diameter	mm
PL	Petiole length	cm
PA	Petiole angle	°
LN	Leaf number	/
LS	Lamina size	mm

Table 3. *F*-values from two-way ANOVAs for total mass (TM) and ANCOVAs for all the other traits, for effects of emergence time (ET), growth stage (GS) and their interactions, with total mass (TM) as a covariate in ANCOVAs. Abbreviations for all traits are in Table 1. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Trait	TM (df = 1)	ET (df = 3)	GS (df = 3)	ET × GS (df = 6)
TM		82.71***	98.11***	13.39***
RMR	13.10***	4.50***	5.68**	3.46**
SMR	38.45***	116.93***	81.84***	29.74***
PMR	0.58	47.64***	28.02***	0.79
LMR	8.69**	133.54***	200.96***	20.10***
REMR	51.31***	9.72***	9.59***	26.26***
RL	2.12	9.83***	15.41***	30.70***
RD	48.23***	32.89***	16.46***	4.83***
LRL	5.97*	9.66***	3.85***	2.84*
LRN	7.45*	0.84	3.90*	2.74*
SL	19.09***	88.96***	111.15***	20.77***
SD	35.98***	112.47***	35.02***	144.83***
PL	6.14*	0.38	0.63	0.10
PA	0.74	55.35***	50.42***	15.18***
LS	47.96***	18.66***	5.19**	19.64***
LN	1.45	17.53***	54.25***	19.23***

Table 4. *F*-values from two-way ANOVAs for total mass (TM) and ANCOVAs for all the other traits, for effects of population density (PD) and growth stage (GS) on all traits, with TM as a covariate in ANCOVAs. Abbreviations for all traits are in Table 1. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Trait	TM (Df = 1)	PD (Df = 2)	GS (Df = 2)	PD × GS (Df = 4)
TM		60.54***	2601.19***	7.71***
RMR	2.21	1.04	32.51***	2.19
SMR	9.71***	17.64***	594.71***	4.88***
PMR	13.40***	0.32	294.00***	1.62
LMR	1.60	17.61***	146.78***	0.67
REMR	2.51	2.16	233.34***	0.42
RL	5.51**	9.03***	54.37***	3.03*
RD	131.22***	135.81***	86.52***	2.24
LRL	0.73	74.13***	57.36***	1.88
LRN	38.97***	42.70***	7.04**	0.38
SL	144.89***	0.72	4782.12***	5.92***
SD	61.30***	47.29***	987.83***	2.13
PL	43.29***	82.10***	286.01***	2.02
PA	16.48***	11.90***	158.54***	1.79
LS	142.26***	74.37***	3214.65***	1.91
LN	42.56***	39.82***	192.95***	4.47***

Table 5. *F*-values from one-way ANOVA for effects of emergence time and population density on the axis 1 and axis 2 components of principle component analysis (PCA) at day 50 and 70 of plant growth.

Stage	Component	Emergence time		Population density	
		<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>
Day 50	Axis 1	63.138	< 0.001	25.585	< 0.001
	Axis 2	8.844	< 0.001	18.054	< 0.001
Day 70	Axis 1	2.815	0.070	8.525	0.001
	Axis 2	2.188	0.124	6.657	0.003

Figures

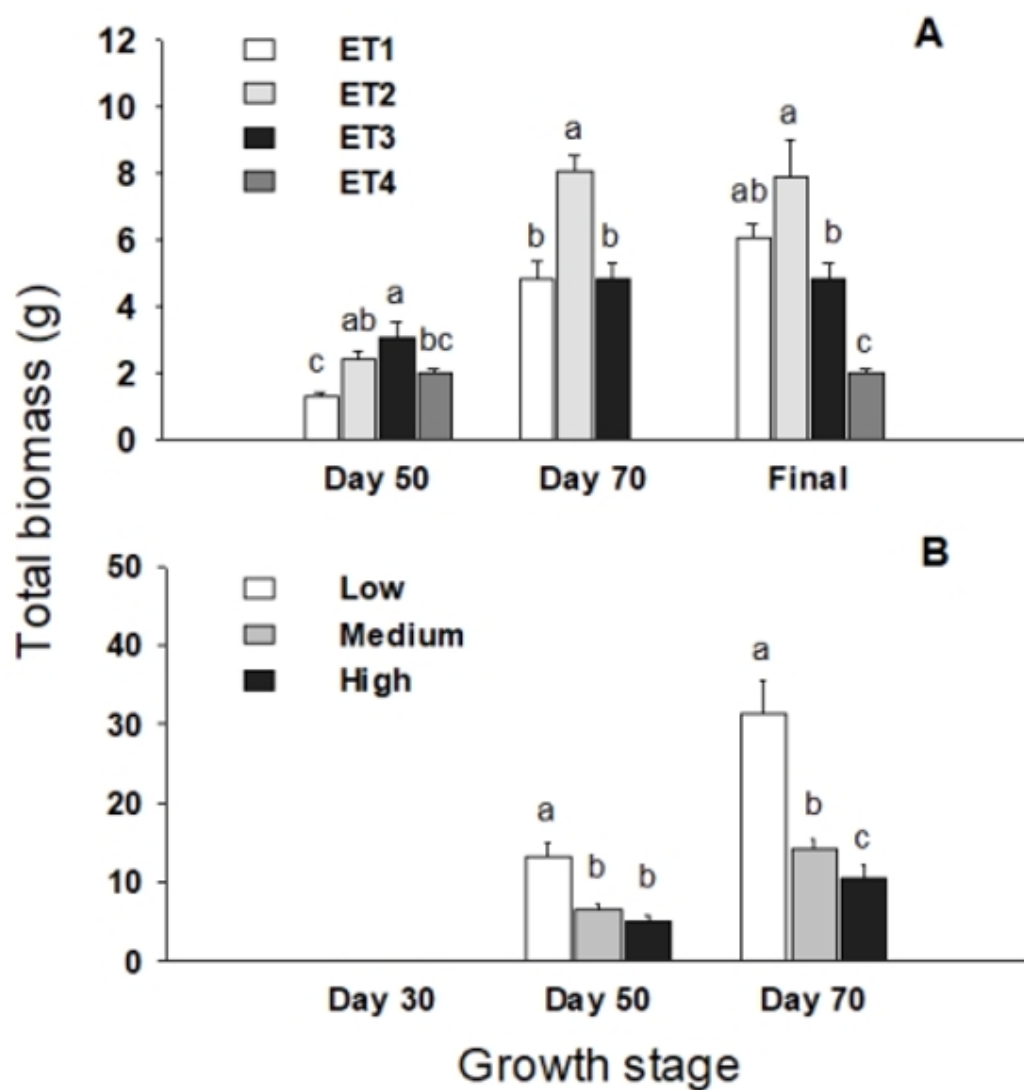


Figure 1

Mean total biomass ($\pm$ SE) of plants that emerged in spring (ET1), late spring (ET2), summer (ET3) and late summer (ET4; A) and plants at low, medium and high densities (B) at different growth stages. Different letters indicate significant difference between emergence or density treatments within growth stages (ANCOVA, LSD, $P < 0.05$).

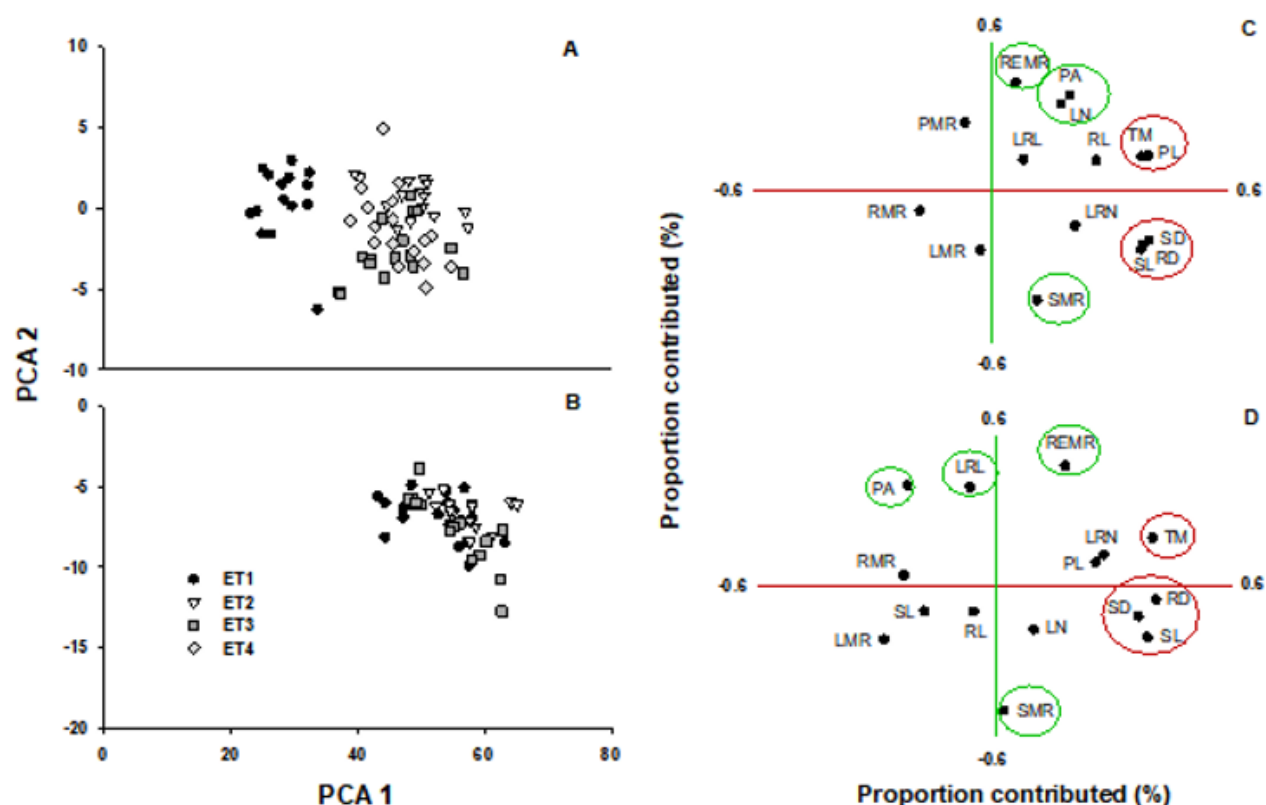


Figure 2

The distribution of individual values of scores along axis 1 and axis 2 of principle component analysis (PCA; A, B) and the proportion contributed by each trait to each component (C, D) for plants that emerged in spring (ET1), late spring (ET2), summer (ET3) and late summer (ET4) at day 50 (A, C) and 70 (B, D) of plant growth. Traits contributing over 30% to either component were circled in red (axis 1) or green (axis 2).

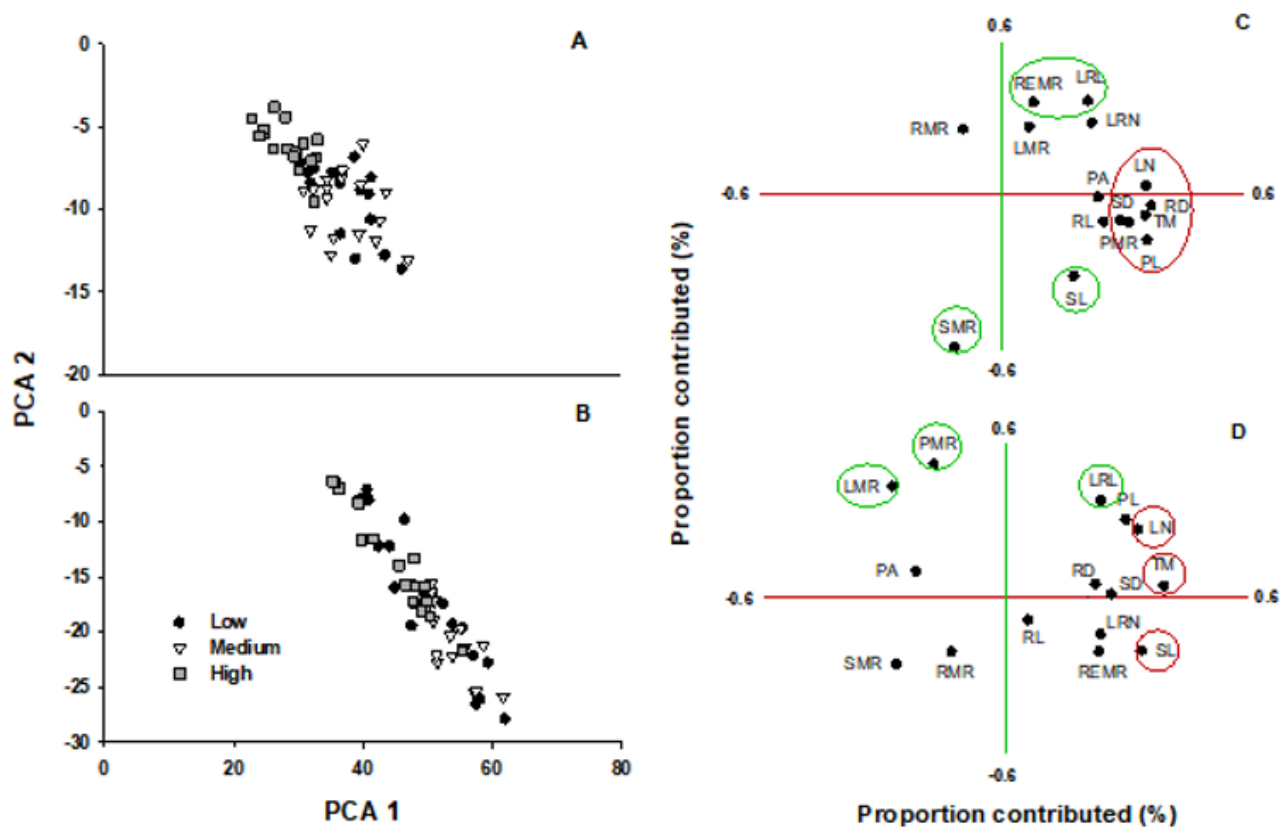


Figure 3

The distribution of individual values of scores along axis 1 and axis 2 of principle component analysis (PCA; A, B) and the proportion contributed by each trait to each component (C, D) for plants at low, medium and high densities at day 50 (A, C) and 70 (B, D) of plant growth. Traits contributing over 30% to either component were circled in red (axis 1) or green (axis 2).

Supplementary Files

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- [SMGTPDmorph2023.8.docx](#)