Chapter 4

Study on seed germination, survival, and growth of the selected wild edible fruit plants

4.1 INTRODUCTION

Understanding the reproductive and vegetative processes of wild edible fruit plants is important to comprehend the population and survival of the species. The essential regulator of life cycle and senescence is crucial for maximizing their economic, ecological, and nutritional potential. These plants have garnered significant attention due to their cultural significance, potential as alternative food sources, and contribution to biodiversity conservation [1–3]. Examining the factors that affect seed germination, survival, and growth is essential for conservation efforts, sustainable harvesting practices, and the promotion of these valuable plant resources.

Seed germination is a critical stage in the life cycle of plants, and its success determines the establishment and growth of plants in their natural habitats. Various factors, including seed dormancy, environmental conditions, and seedling nutrition influence the seed germination process. Species can exhibit different seed dormancy mechanisms, affecting the timing and rates of germination [4]. Environmental factors, such as temperature, moisture availability, light conditions, and soil characteristics play crucial roles in germination success [5,6]. Recognizing the germination requirements and mechanisms of wild edible fruit plants is even more important to provide insights into their adaptive strategies and inform propagation and cultivation practices. Survival and growth of wild edible fruit plants are the result of complex processes in which plants are influenced by complex environmental interactions. Factors like competition with other plant species, herbivory, disease, and abiotic stresses significantly impact their survival rates and growth patterns [7–9]. Assessing the responses and resilience of these plants to environmental factors is vital for their long-term survival and sustainable utilization. Furthermore, understanding their growth characteristics are important for horticultural practices, agroforestry systems, and efforts to restore forest. These features include growth rates, biomass accumulation, root development, and responses to management interventions [10].

In this study, shade netting was employed to evaluate the growth rate of selected fruit species. Shade netting is a commonly used technique in agriculture and horticulture to modify microclimatic conditions and optimize plant growth [10,11]. Shade netting alters microclimatic conditions, such as light quantity, quality, and canopy and soil temperature [12]. Changes in light conditions can affect seed germination rates, as well as the subsequent survival and growth of seedlings. Moreover, shade nets modify the distribution of light within the plant canopy, promoting uniform illumination and reducing the risk of leaf sunburn or scorching. These modifications have significant impacts on photosynthesis, biomass accumulation, and fruiting patterns in wild edible fruit plants [13].

The objective of the study is to evaluate how shade nets affects microclimatic conditions and physiological characteristics of the plants. It is essential to assess the microclimatic conditions created by the nets to determine their suitability for specific fruit crops, taking into account factors such as the required degree of shading for optimal light levels [14]. Through the examination of seed germination, survival, and growth of selected wild edible fruit plants under shade netting, it is possible to get valuable insights into the specific effects of shade nets on these plant species. This knowledge can be used as a tool to develop shade netting techniques that will optimize cultivation, maximize yield potential, and ensure sustainable production practices.

4.2 MATERIALS AND METHODS

A total of 15 wild edible fruits such as *Antidesma bunius* (L.) Spreng, *Averrhoa carambola* L., *Dillenia indica* L., *Elaeocarpus floribundus* Bl., *Ficus cunia* Buch. -Ham.ex Roxb, *Garcinia pedunculata* Roxb., *Garcinia xanthochymus* Hook.f., *Microcos paniculata* L., *Phylanthus emblica* L., *Psidium guajava* L., *Rhus semialata* Murr., *Solanum betaceum* Cav., *Spondius pinata* (L.f.) Kurz, *Vangueria spinosa* (Roxb. ex Link) Roxb, and *Zizyphus mauritiana* Lamk. were collected based on criteria such as rituals and cultural significance, seasonal availability, market value and rarity in natural population during 2019 - 2020 to examine seed germination, seedling survival and growth under different shade netted experimental house.

Healthy seeds were extracted from the parent fruits and air-dried before being stored in an airtight container. Due to the impact of the COVID-19 pandemic during January-June 2021, many seeds were either spoiled or affected, resulting in only seven species being suitable for conducting germination, survival, and growth study: *Elaeocarpus floribundus, Microcos paniculata, Phyllanthus emblica, Rhus semialata, Solanum betaceum, Vangueria spinosa*, and *Ziziphus mauritiana*. Prior to commencing the experiment, the seeds underwent a water treatment, wherein they were submerged in water for a period of 24 hours as recommended by FAO, 1992 [15]. This treatment was implemented to facilitate the germination process.

The experiments were conducted at an experimental site within the premises of Dept. of Environmental Science at Tezpur University during July to October 2021. The experimental sites have three shade netting houses with varying levels of shade (25%, 50%, and 75%), constructed by utilizing greenhouse shade netting. The purpose of conducting experiment in different shade levels of 25%, 50% and 75% is to identify the best suitable microsite for seed germination, seedling survival and growth of these selected 15 wild edible fruits. Throughout the study duration, daily measurements for light intensity (lux), temperature (℃), humidity (%), and soil temperature (℃) were taken in all the three shade netting houses.

Germination trials were conducted for the seven fruit species using sterilized soil under three different net shading houses (25%, 50%, and 75%). 20 seeds of each species were sown for the purpose of study. It was observed that the germination percentage was considerably low exhibiting <20 % germination rate for all species under all the three houses. As a result, the 20 seeds of each plant were exclusively sown in open conditions to facilitate germination. Germination periods were recorded, and the germination percentage was calculated. There was on an average above 50 % germination rate for all the plants, with variability in days of germination. The survivability of seedlings after germination was monitored for a period of 10 days. Following the 10-day germination phase, 10 seedling of each species was transplanted under the three different shade levels (25%, 50%, and 75%) to evaluate their growth over a 90-day post-germination period.

4.2.1 Measurements

Climatic measurements: The microclimatic variables inside the shade netting house were monitored, and the following data were recorded: (a) Light intensity in lux, measured using a luxmeter; (b) air temperature in ^{O}C; (c) humidity in %, measured using a humidity sensor placed above 1.5 m above the ground; and (d) soil temperature using soil thermometer.

Crop measurements: For measurement of various growth parameters, non-destructive methods were conducted. At intervals of ten days over a 90-day period, five (05) seedlings of each plant were observed for various growth parameters, including plant height, total leaf count, leaf length, and leaf width. The root-shoot ratio was calculated after 10 and 90 days of germination, and the total biomass of the species was measured. Photosynthesis rate was determined using an infrared gas analyser (IRGA) after 30 days of transplantation. The total biomass of the plants after 90 days of germination under different natural light conditions was measured. The pigment content (chlorophylls and total carotenoids) in immature (after 10 days of germination) and mature leaves (after 30 days of transplantation) grown under different light conditions was compared, and possible correlations between physiological parameters were analysed. The leaf length and leaf width were measured using 10 healthy leaves. Leaf area was calculated using the leaf length and leaf width data. All measurements of plant growth parameters were recorded in a dedicated field observation logbook.

Relative growth rate: The determination of the relative growth rate (RGR) for individual seedlings in terms of height (RGRH) and total leaf area (RGRA) was conducted based on Eq. 4.1, as presented by Hunt in 1982 [16].

$$RGR(t_{n-1} - t_n) = \frac{[\ln S(t_n) - \ln S(t_{n-1})]}{t_n - t_{n-1}} \tag{4.1}$$

Here, S represents the plant size, specifically the height (cm) or total leaf area (cm^2), and t refers to the time elapsed in months. The calculated RGRH and RGRA values were determined for each observation time interval, such as between t_0 and t_1 denoted as RGRH1 and RGRA1, between t_1 and t_2 denoted as RGRH2 and RGRA2, and between t_2 and t_3 denoted as RGRH3 and RGRA3. To assess temporal changes in RGRH and RGRA, the values of RGRHs and RGRAs were calculated accordingly.

Biomass measurement: The total biomass of the plants was determined using the oven-dry method [17]. After 90 days of germination, the plants were uprooted, cleaned of any debris, cut into small pieces, and weighed. The plant samples were then dried at a temperature of 40 to 45^{o}C until a constant weight was obtained.

Measurement of pigment content: The chlorophyll (chl a, chl b, and total chl) and total carotenoids content of the immature and mature leaves were evaluated using the methods described by Arnon (1994) [18] and Nagata and Yamashita (1992) [19], respectively .

Extraction of chlorophyll and carotene**:** One gram of finely cut fresh leaves was taken and ground with 20-40 ml of 80% acetone. The mixture was then centrifuged at 5000-10000 rpm for 5 minutes. The supernatant was transferred, and the process was repeated until the residue became colourless. The absorbance of the solution was measured at 645nm, 663nm, 505nm, and 453nm against a blank solvent (acetone).

Estimation of pigment content: The concentrations of chlorophyll a, chlorophyll b, total chlorophyll, and total carotenoids were calculated using the following equations (4.2 - 4.5):

Chlorophyll a: 12.7(A663) – 2.69(A645) (4.2)

Chlorophyll b: 22.9(A645) – 4.68(A663) (4.3)

Total Chlorophyll: 20.2(A645) + 8.02(A663) (4.4)

Total carotenoid: 0.216(A663) – 1.22(A645) – 0.304(A505) + – 0.452(A453) (4.5)

Analysis of photosynthesis rate using IRGA: Healthy leaves were carefully chosen from the plants, ensuring that they were clean and free from any damage or disease. The IRGA instrument was set up in accordance with the manufacturer's instructions, including calibration and ensuring sufficient battery charge. The leaf chamber of the IRGA was securely attached to the selected leaf, completely enclosing it to create a sealed environment for gas exchange measurements. Once the leaf was stabilized, the measurement was initiated by activating the IRGA. The IRGA instrument recorded real-time measurements of photosynthesis rate, specifically the rate of CO_2 uptake by the leaf during photosynthesis. The photosynthesis rate was reported as the rate of CO_2 assimilation in micromoles per square meter per second. Multiple measurements were taken at different time points to ensure data accuracy. The data obtained from the IRGA instrument were analysed, and the average photosynthesis rate was calculated.

4.3 RESULT

4.3.1 Climatic measurements

Climatic variables, light intensity (lux), air temperature (^oC), humidity (%), and soil temperature (^oC) were recorded inside the shade netting house at Tezpur University during the study period from July to October 2021. The measurements were taken at three different shade levels: 25%, 50%, and 75% and the recorded values are presented in Table 4.1.

The observations revealed variations in light intensity across the different shade percentages, with higher values recorded in September and October. The range of light intensity in 25% shade varied from 1332.83 to 32004 lux; in 50% shade it was 407.17 to 16999.00 lux; and in 75% shade it varied from 324.83 to 13720.83 lux. The air temperature remained relatively stable throughout the study period, with slight fluctuations. In the 25% shade, the temperature ranged from 29.43 to 32.54℃. For the 50% shade, the temperature varied from 28.40 to 31.86℃. In the case of the 75% shade, the temperature ranged from 27.55 to 30.22℃. Although the humidity levels fluctuated slightly, it maintained within a moderate range (72.52 to 85.96%). In the 25% shade, the humidity ranged from 72.52 to 79.36%. For the 50% shade, the range was between 77.66 and 82.95%. As for the 75% shade, the humidity levels varied from 80.35 to 85.96%. Regarding the soil temperature, it remained relatively consistent throughout the study period. In the 25% shade, the range of soil temperature was between 30.05 and 31.48℃. For the 50% shade, it ranged from 29.25 to 31.18℃. Lastly, in the 75% shade, the soil temperature varied from 28.44 to 31.16℃.

These climatic measurements provide valuable information about the environmental conditions in which the plants were grown and can contribute to a better understanding of their growth and development.

Table 4.1 Climatic variables recorded inside the shade (25%, 50% and 75%) netting houses.

In the year 2021	**Light intensity (lx)**			**Temp.(℃)**			**Humidity (%)**			**Soil Temp.(℃)**		
	25%	**50%**	**75%**	**25%**	**50%**	**75%**	**25%**	**50%**	**75%**	**25%**	**50%**	**75%**
July	1332.83	407.17	324.83	29.43	28.40	27.55	78.83	82.95	83.93	30.17	30.00	29.25
August	9295.05	5270.81	4452.14	32.28	31.42	30.22	79.33	82.20	85.85	31.48	31.18	31.16
September	20990.34	12036.63	9107.56	31.26	30.91	28.90	79.36	82.84	85.96	30.11	29.77	29.77
October	32004.17	16990.00	13720.83	32.54	31.86	30.49	72.52	77.66	80.35	30.05	29.25	28.44

4.3.2 Germination percentage and survivability

The germination percentage and survivability after 10 days of germination were recorded for the seven studied fruit species (Table 4.2). Among the seven selected species, four species (*M. paniculata*, *S. betaceum*, and *Z. mauritiana*) exhibited the highest germination percentages (100%). *P. emblica* recorded 90%, *R. semialata* with 55% and *V. spinosa* showed 50% germination rate. *E. floribundus* did not germinate at all. The survivability rate after 10 days of germination was high for all species except *R. semialata*. A survivability rate above 50% after 10 days of germination was considered high, while a rate below 50% was considered low, and a rate below 20% was considered a very low survivability rate.

Table 4.2 Germination percentage and survivability after 10 days of germination of fruit species

Fruits	Germination Period	Germination Percentage (%)	Survivability after 10 days of germination
Elaeocarpus floribundus	Not germinated	---	---
Microcos paniculata	14 to 17 days	100%	High (>50%)
Phyllanthus emblica	7 - 9 days	90%	High (>50%)
Rhus semialata	10 -20 days	55%	Very low (<20%)
Solanum betaceum	10 -12 days	100%	High (>50%)
Vangueria spinosa	43 - 51 days	50%	High (>50%)
Ziziphus mauritiana	23 -32 days	100%	High (>50%)

4.3.3 Root-shoot ratio and total biomass

The root-shoot ratio was measured for each fruit species after 10 days of germination and 90 days of germination, as shown in Table 4.3. This ratio is an important indicator of root density and nutrient uptake efficiency for plant growth. It was observed that all fruit species exhibited the highest root-shoot ratio after 10 days of germination. However, it is noteworthy that *R. semialata* had a relatively high root-shoot ratio after

10 days but did not survive after transplantation in any of the shade conditions. This outcome may be attributed to various biotic and abiotic factors influencing its growth and development.

Table 4.3 Root-shoot ratio after 10 days and 90 days of germination

Fruits	10 days after germination	90 days after germination		
		75% Shade	50% Shade	25% Shade
Solanum betaceum	0.49	0.45	0.38	0.37
Microcos paniculata	0.63	0.50	0.35	0.22
Phyllanthus emblica	0.47	0.24	0.17	0.28
Rhus semialata	0.54	---	---	---
Ziziphus jujube	0.60	0.26	0.27	0.54
Vangueria spinosa	0.55	0.30	0.46	0.45

The total biomass of studied plants was measured after 90 days of germination. For 25% and 50% shade, *Z. mauritiana* showed the maximum biomass, while *V. spinosa* showed the maximum in 75% shade (Table 4.4). Productivity increases proportionately with increasing biomass. In contrast to *Z. mauritiana*, other fruit species showed maximum total biomass in 25% shade netting house.

Table 4.4 Total biomass recorded after 90 days of germination in different shade houses.

Fruits	Total biomass (g)		
	25% Shade	50% Shade	75% Shade
Microcos paniculata	2.81 ± 0.73	1.00 ± 0.34	1.25 ± 0.18
Phyllanthus emblica	5.38 ± 1.19	1.35 ± 0.41	5.61 ± 0.84
Solanum betaceum	3.25 ± 0.42	2.07 ± 0.36	1.65 ± 0.64
Vangueria spinosa	24.13 ± 1.02	5.18 ± 0.84	18.41 ± 1.50
Ziziphus mauritiana	10.90 ± 3.90	11.74 ± 0.88	2.60 ± 0.58

Moreover, Table 4.5 presents the Pearson's correlations among the climatic variables, root-shoot ratio, and biomass. The findings reveal positive correlations between light intensity and temperature, as well as light intensity and total biomass, with correlation coefficients of 0.72 and 0.71 respectively, both statistically significant at a significance level of $p < 0.01$. Conversely, a significant negative correlation is observed between light intensity and humidity, with a correlation coefficient of -0.73 ($p < 0.01$). Furthermore, temperature and humidity display a negative correlation of -0.66 ($p < 0.05$). Additionally, humidity and total biomass exhibit a negative correlation of -0.67 at a significance level of $p < 0.05$. Similarly, soil temperature and root-shoot ratio also demonstrate a significant negative correlation, with a correlation coefficient of -0.58 at $p < 0.05$.

Table 4.5 Pearson correlation between climatic measures, root-shoot ratio and total biomass

	Light intensity	Temperature	Humidity	Soil temperature	Root/shoot	Total biomass
Light intensity	1					
Temperature	.723**	1				
Humidity	-.735**	-.663*	1			
Soil temperature	-.180	.319	.091	1		
Root/shoot	.377	-.185	-.129	-.583*	1	
Total biomass	.714**	.477	-.666*	-.278	.176	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

4.3.4 Growth rate parameters under three different shade netting houses

The growth rate parameters, including height, total leaf count, leaf area was assessed for five surviving wild edible fruit species (*Microcos paniculata*, *Phyllanthus emblica*, *Solanum betaceum*, *Vangueria spinosa*, and *Ziziphus mauritiana*) grown under three different shade netting houses. The determination of leaf area was conducted, as it plays a significant role in the photosynthetic capacity of the plants.

Figs. 4.1 to 4.3 depict the growth trends of all the studied fruit species under three different shade houses. *Microcos paniculata,* observed increasing growth in terms of height, total leaf count and leaf area during their growing period. However, the leaf area showed minimal variation across the different shade houses, although the highest absolute leaf area (14.03 cm^2) at the end of observation (90 days) was observed in the 75% shade condition. *Microcos paniculata* showed maximum leaf count (69) when exposed to the 25% shade condition. Variation in leaf count was observed under 50% and 75% shade. Specifically, plants in the 75% shade condition experienced a substantial decrease in leaf count, declining from 15 on the 70th day to 10 on the 80th day, before gradually recovering to 15 by the 90th day.

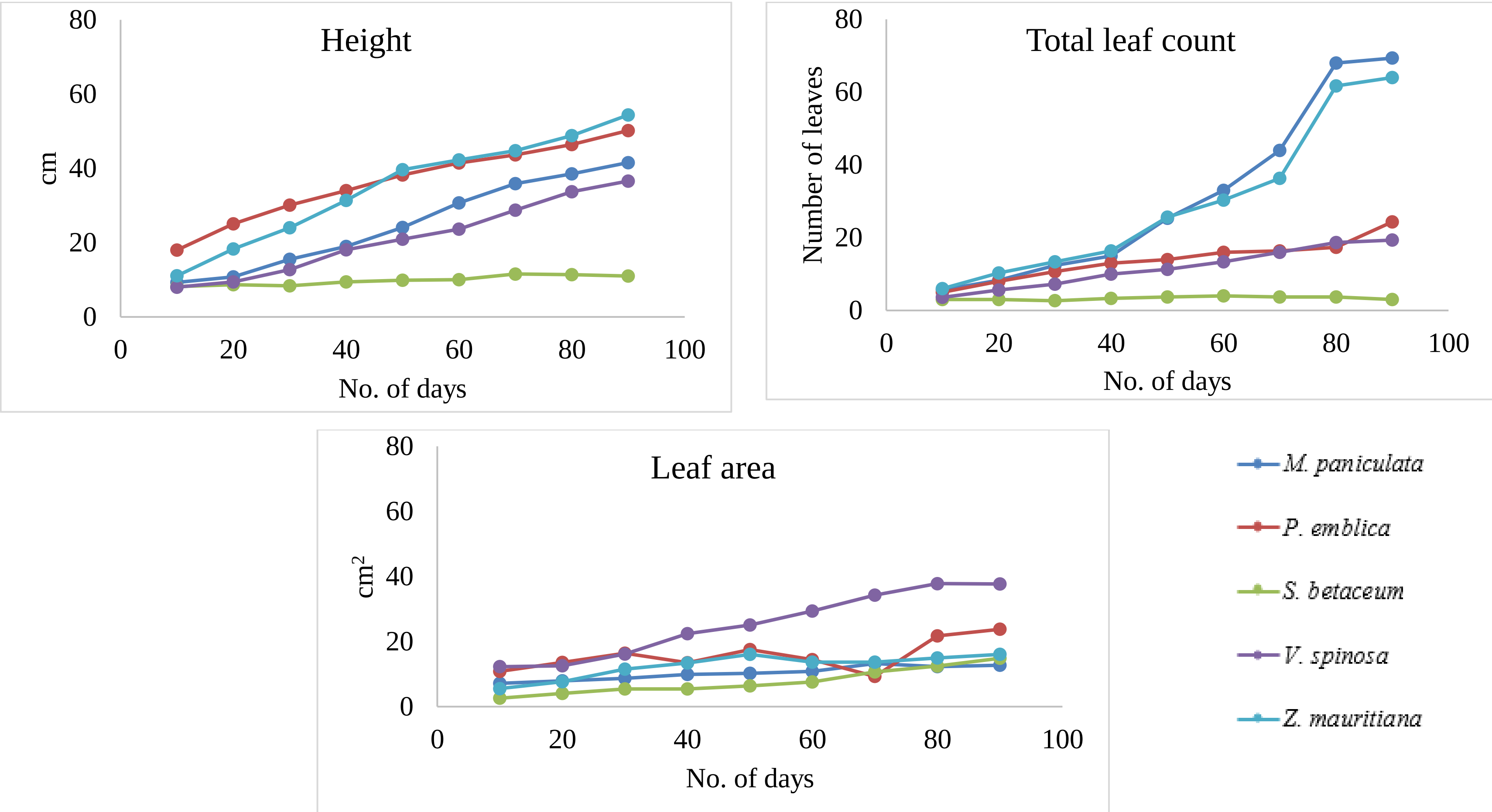

Fig. 4.1 Growth in plant height, total leaf count, and leaf area during the study period in 25% shade house.

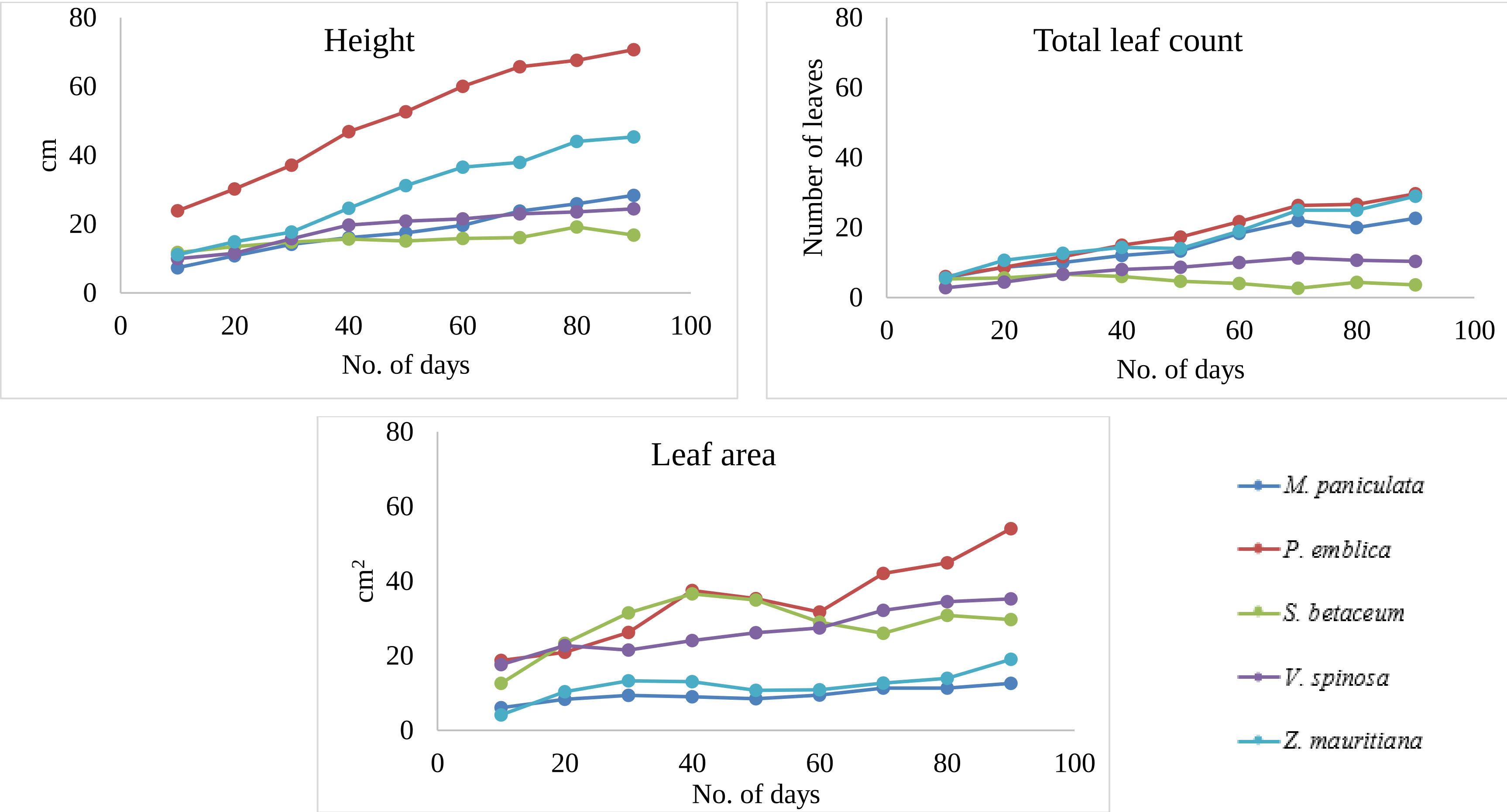

Fig. 4.2 Growth in plant height, total leaf count, and leaf area during the study period in 50% shade house.

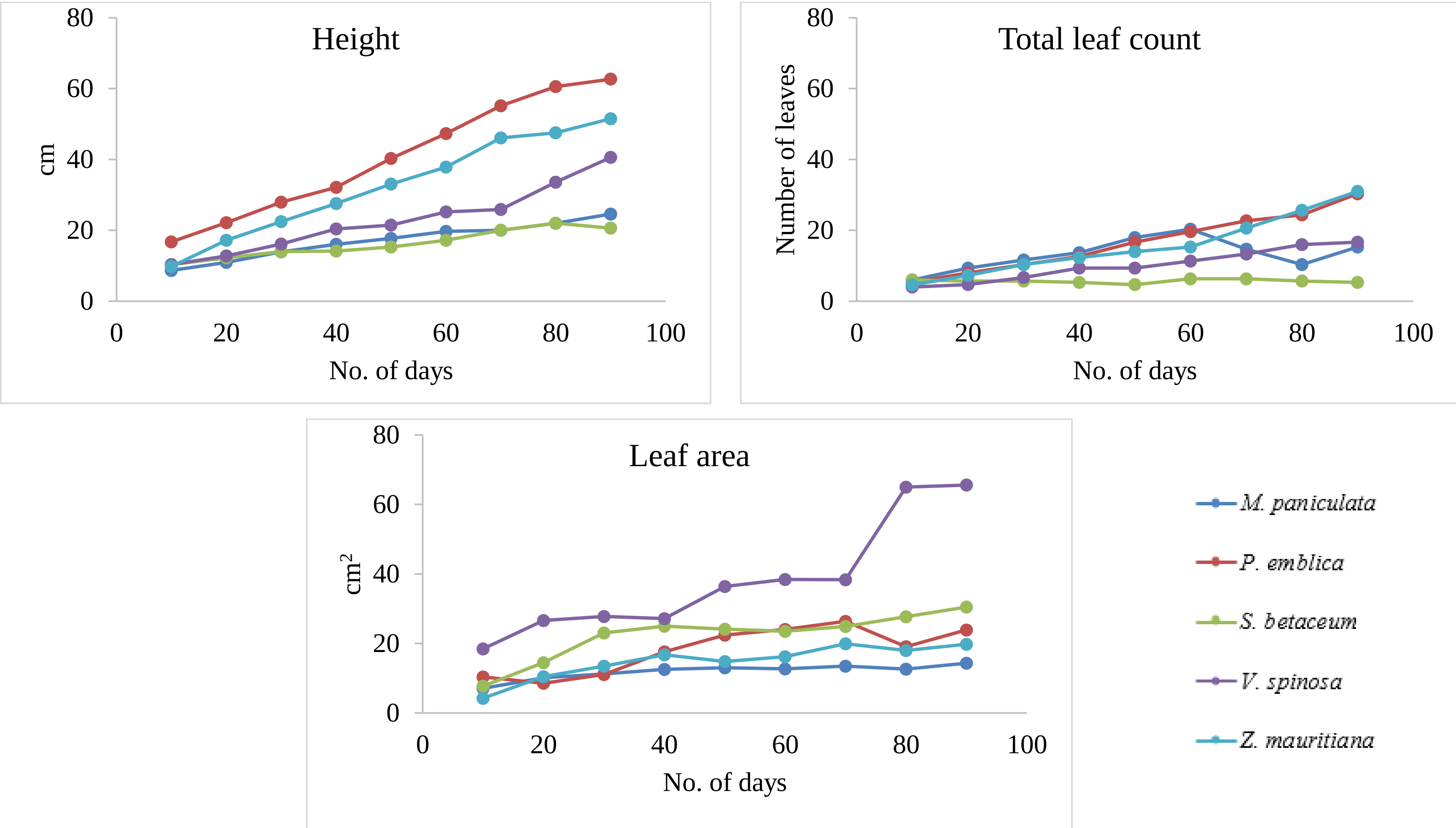

Fig. 4.3 Growth in plant height, total leaf count, and leaf area during the study period in 75% shade house.

P. emblica, demonstrated a similar trend to that of *Microcos paniculata*. As the number of days increased, both the height and total leaf count of *P. emblica* exhibited an upward trajectory. Notably, fluctuations in leaf area were observed across different shade percentages. The highest leaf area (51.71 cm^2) was recorded under the 50% shade condition, while the lowest leaf area (23.68 cm^2) was observed under the 75% shade condition on the 90th day. *P. emblica* showed highest absolute height in 50% (70.70 cm) followed by 62.67 cm in 75% shade having same number of leaf number (30 each), while still maintaining growth under 25% shade with 50.2 cm and 24 leaf number. These findings highlight the environmental adaptability of *P. emblica*, emphasizing its versatility and resilience in response to varying environmental conditions.

The growth trends of *S. betaceum* under varying shade conditions. Throughout the 90-day growth period, all examined growth parameters exhibited an increasing pattern as the shade percentage increased. *S. betaceum* attained its maximum absolute height (20.67 cm), highest leaf count (5), and maximum leaf area (29.25 cm^2) when exposed to the 75% shade condition. Notably, the temporal pattern of leaf area was found to be similar between the 50% and 75% shade conditions.

The growth characteristics of *V. spinosa* under various shade conditions indicate that the plant displayed consistent growth in terms of height and total leaf count throughout the 90 day duration. *V. spinosa* reached its absolute height (40.57 cm) and leaf area (61.29 cm^2) under the 75% shade condition, while the highest leaf count (19) was observed under the 25% shade condition. It is worth noting that under the 75% shade condition, a significant decline in leaf area was observed after the 70th day.

Throughout the 90 day period, *Z. mauritiana* displayed consistent growth in terms of height and total leaf count across all shade levels (25%, 50%, and 75%). Notably, absolute heights were observed in both the 25% shade condition (54.4 cm) and the 75% shade condition (51.5 cm). The absolute total leaf count was significantly higher in the 25% shade condition (64) compared to the 50% shade condition (29) and the 75% shade condition (31). While there were slight variations in absolute leaf area, the highest leaf area (12.82 cm^2) was observed in the 75% shade condition, followed by the 50% shade condition (12.43 cm^2).

4.3.5 Relative growth rate under three different shade netting houses

The relative growth rate of the individual seedlings in terms of height (RGRH) and the relative growth rate of the total leaf area (RGRA) were determined in order to quantify the differential growth rate increment in response to varied shade and days of growing period.

Fig. 4.4 and 4.5 showed the temporal changes (daily) in seedling growth, focusing on the relative growth rate in terms of height (RGRH) and leaf area (RGRA) in 10 days of interval for 90 days. Fig. 4.6 and 4.7 showed the temporal changes (monthly) in seedling relative growth rate in terms of height (RGRH) and leaf area (RGRA) recorded in three months. Similar growth pattern in terms of relative growth rate in terms of leaf area in months was observed under all the three shade houses for most of the studied fruit plants. However, it was observed that there was declined growth rate during the months (Aug. – Sept.) and those increases in the following months (Sept. – Oct.).

In the 25% shade condition, all species experienced an increase in height over time, with varying rates of growth. In July-August, *S. betaceum* had RGRH (cm cm^{-1} mo^{-1}) value of 1.91, while *M. paniculata, P. emblica, V. spinosa*, and *Z. mauritiana* had RGRH (cm cm^{-1} mo^{-1}) values of 2.51, 3.08, 2.32, and 2.89, respectively. In August-September, the RGRH (cm cm^{-1} $mo^{-1)}$ values increased for all species, with *S. betaceum* at 2.08, *M. paniculata* at 3.11, *P. emblica* at 3.36, *V. spinosa* at 2.86, and *Z. mauritiana* at 3.38. By September-October, further growth was observed, with RGRH (cm cm^{-1} mo^{-1}) values of 2.15 for *S. betaceum*, 3.36 for *M. paniculata*, 3.53 for *P. emblica*, 3.25 for *V. spinosa*, and 3.61 for *Z. mauritiana*.

While, in the 50% shade, *S. betaceum* exhibited minimal growth rate in terms of height (RGRH) value of 0.01 cm cm^{-1} mo^{-1} in July-August, while *M. paniculata, P. emblica*, and *Z. mauritiana* showed relatively higher growth rates of 0.03, 0.02, and 0.02 cm cm^{-1} mo^{-1}, respectively. *V. spinosa* did not show any increment in growth (RGRH) and remained stable during August-September as well as in September-October.

In the 75% shade condition, *S. betaceum* exhibited minimal growth with a RGRH (cm cm^{-1} mo^{-1}) value of 0.01 in July-August, while *M. paniculata, P. emblica*, and *V. spinosa* showed consistent increment in growth rates of 0.02 cm cm^{-1} mo^{-1}. *Z. mauritiana* displayed a higher initial growth rate of 0.03 in July-August but experienced a slight decrease in their increment in growth to 0.01 cm cm^{-1} mo^{-1} in August-September and maintained that level of growth in September-October.

Regarding the relative growth rate in terms of leaf area (RGRA), lowest RGRA was observed in 25% shade condition for all studied species. *S. betaceum* exhibited a relatively higher RGRA (cm^2 cm^{-2} mo^{-1}), indicating consistent growth in leaf area (0.03, 0.02, 0.02) in the 25% shade condition. *M. paniculata* showed similar increment (RGRA: 0.01, 0.01, 0 cm^2 cm^{-2} mo^{-1}) in first two months them declines with no increment in growth rate. *P. emblica* initially had a positive RGRA (cm^2 cm^{-2} mo^{-1}) value, but it experienced a decline in the second month and a slight increment in the third month (0.02, -0.02, 0.01). A positive RGRA (cm^2 cm^{-2} mo^{-1}) was also found in *Z. mauritiana* in the first month, no growth in the second month, and a slight increment in the third month (0.04, -0.02, 0.01). *V. spinosa* demonstrated consistent RGRA (cm^2 cm^{-2} mo^{-1}) values close to zero, suggesting minimal relative growth rate in terms of i leaf area (0.03, 0.02, 0).

Under 50% shade, *M. paniculata* (0.01, 0.01, 0.01cm^2 cm^{-2} mo^{-1}) and *Z. mauritiana* (0.03, 0, 0.03cm^2 cm^{-2} mo^{-1}) displayed positive RGRA values in all observation time, indicating a positive increment in relative growth rate in terms of leaf area. *S. betaceum* (0.03, -0.02, 0 cm^2 cm^{-2} mo^{-1}) and *P. emblica* (0.02, -0.01, 0.02 cm^2 cm^{-2} mo^{-1}) initially showed a decline in RGRA but recovered within a month. Similarly, *V. spinosa* (-0.01, 0, 0 cm^2 cm^{-2} mo^{-1}) exhibited a decline in leaf area, but it remained stable with no RGRA during Aug.-Sept.

In 75% shade, all the fruit species showed positive relative growth rate in leaf area, indicating increased in RGRA having *M. paniculata* (0.05, 0, 0.01cm^2 cm^{-2} mo^{-1}), *P. emblica* (0.01, 0, 0.01 cm^2 cm^{-2} mo^{-1}), *S. betaceum* (0.03, 0.01, 0.02 cm^2 cm^{-2} mo^{-1}), *V. spinosa* (0, 0.01, 0 cm^2 cm^{-2} mo^{-1}), and *Z. mauritiana* (0.03, 0.01, 0.01cm^2 cm^{-2} mo^{-1})

The Pearson's correlation was analysed between light intensity recorded in the three different shade netting houses, and plant species' growth parameters. Table 4.6 gives the Pearson's correlation values for plant heights, Table 4.7 for total leaf count and Table 4.8 for leaf area. It was observed that there was a significant positive correlation between light intensity in different shading and plant height in most studied plant species. The correlation coefficients ranged from 0.833 to 0.998, indicating a strong positive correlation. The correlation between light intensity in different shading and total leaf count also varied among different plant species. Some species showed a negative correlation, while others showed a positive correlation. The correlation coefficients ranged from -0.718 to 0.997, indicating varying degrees of correlation. There was a significant positive correlation between light intensity in different shading and leaf area. The correlation coefficients ranged from 0.338 to 0.971, indicating varying degrees of correlation.

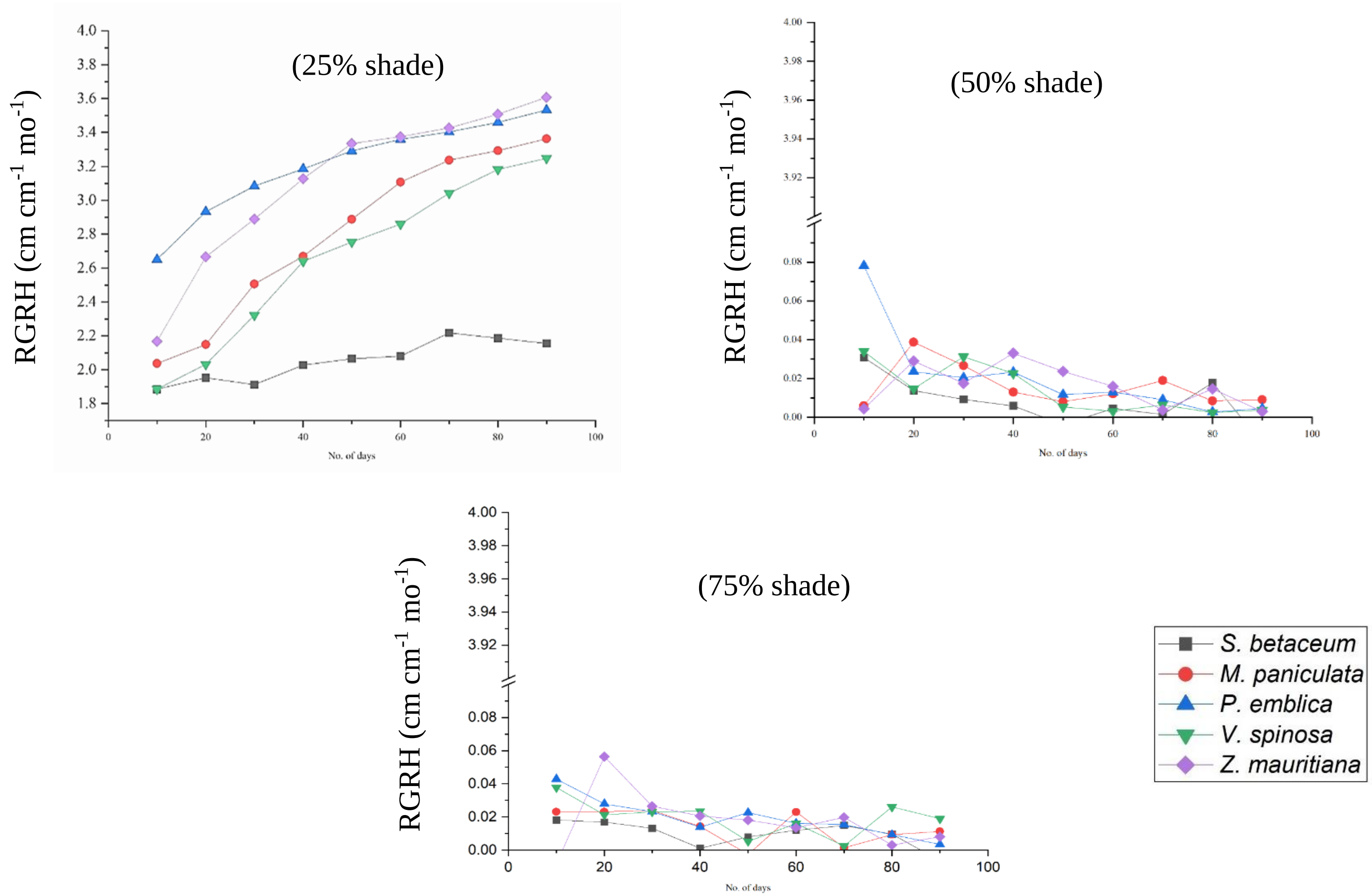

Fig. 4.4 Relative growth rate of seedlings in terms of height (RGRH), under 25% shade, 50% shade, and 75% shade.

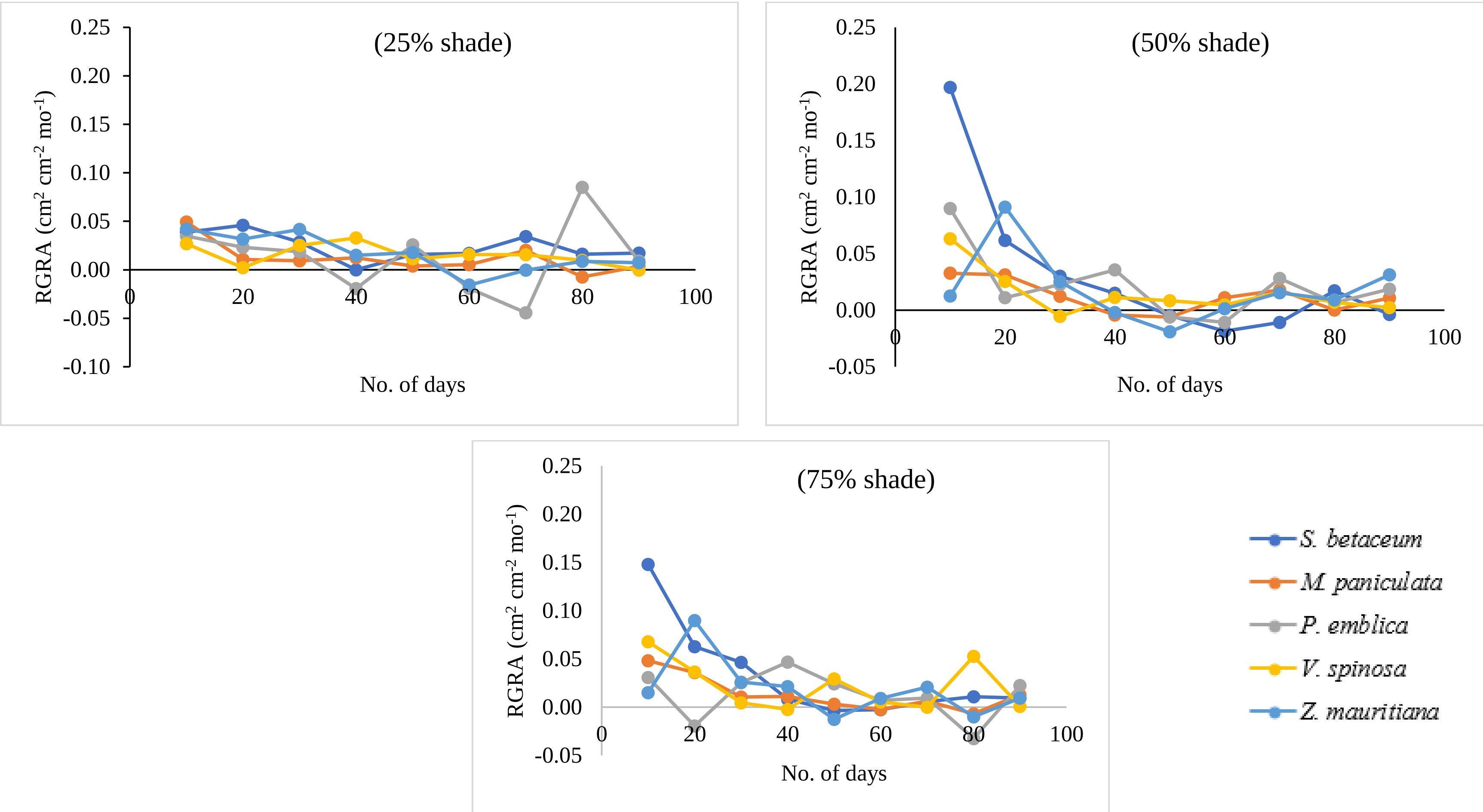

Fig. 4.5 Relative growth rate of seedlings in terms of leaf area under 25% shade, 50% shade, and 75% shade.

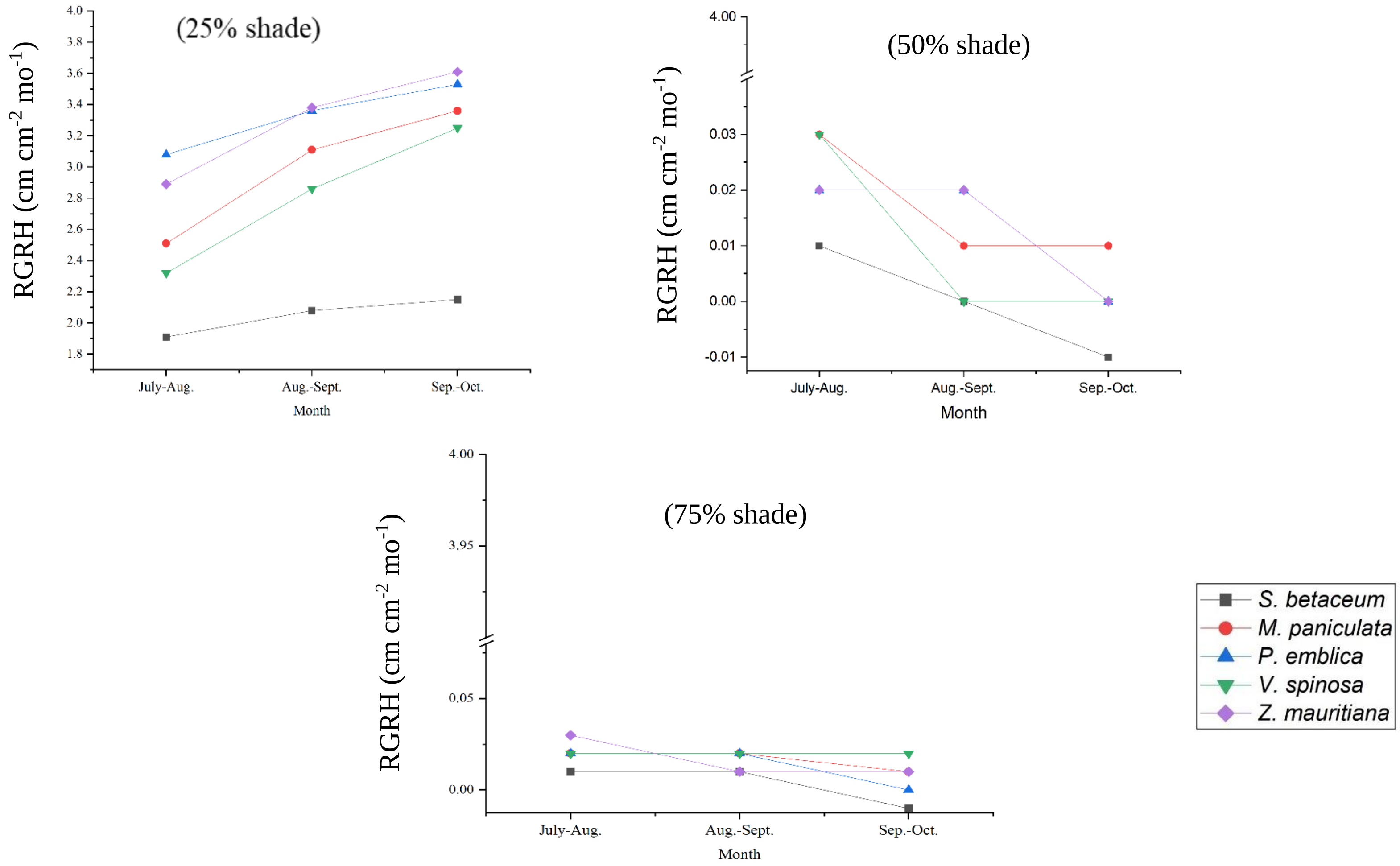

Fig. 4.6 Relative growth rate of seedlings in terms of leaf height under 25% shade, 50% shade and 75% shade.

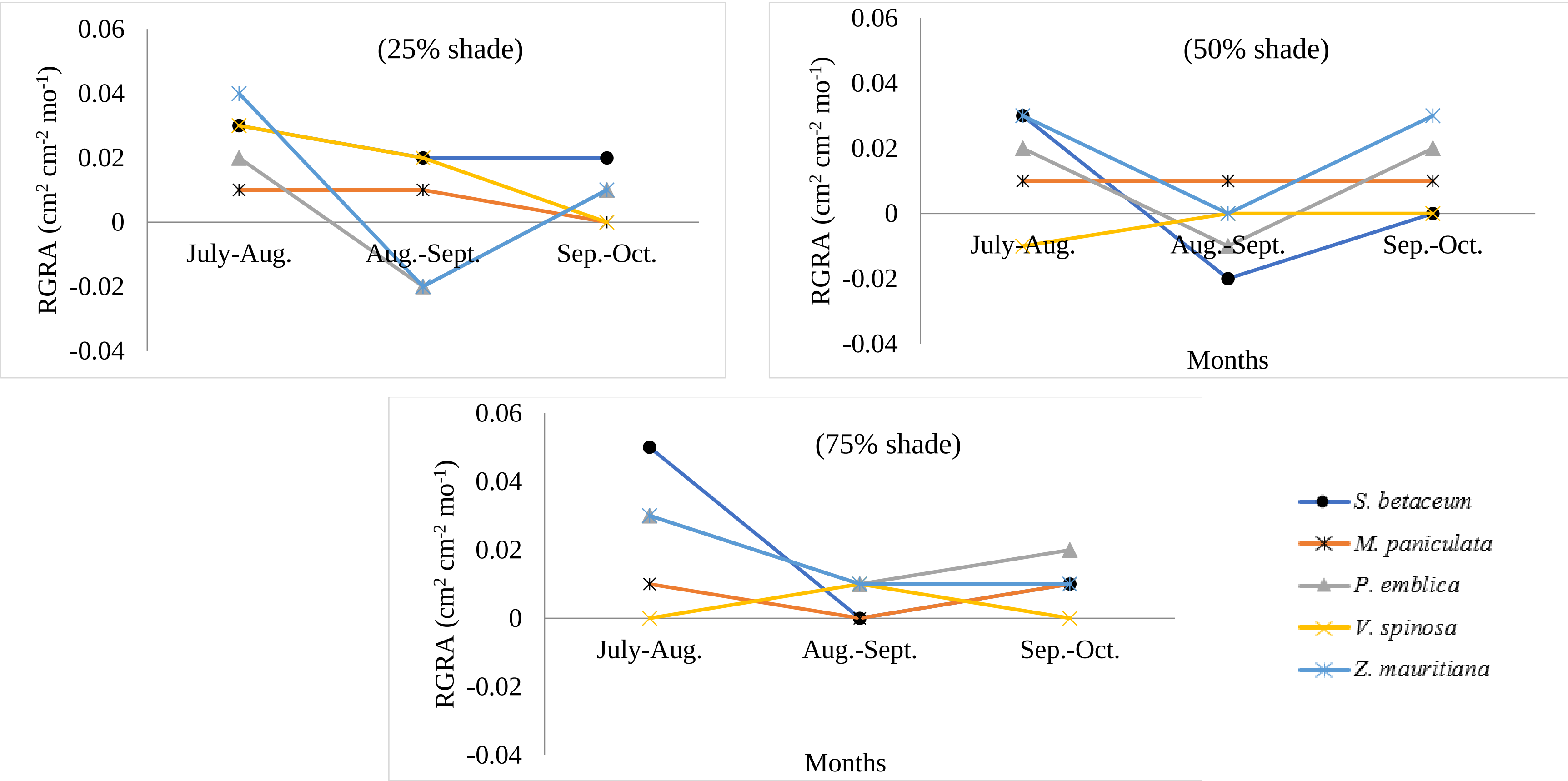

Fig. 4.7 Relative growth rate of seedlings in terms of leaf area (a) 25% shade (b) 50% shade (c) 75% shade.

Table 4.6 Pearson correlation between light intensity, recorded in three different shade netting houses, and plant' heights.

	Species		P1			P2			P3			P4			P5	
	Shade %	25%	50%	75%	25%	50%	75%	25%	50%	75%	25%	50%	75%	25%	50%	75%
P1	25%	1														
	50%	.833**	1													
	75%	.955**	.918**	1												
P2	25%	.954**	.856**	.977**	1											
	50%	.937**	.894**	.979**	.985**	1										
	75%	.898**	.887**	.954**	.976**	.987**	1									
P3	25%	.919**	.893**	.954**	.972**	.984**	.984**	1								
	50%	.952**	.880**	.962**	.985**	.979**	.978**	.991**	1							
	75%	.958**	.880**	.986**	.998**	.990**	.976**	.979**	.987**	1						
P4	25%	.944**	.877**	.971**	.991**	.990**	.976**	.970**	.976**	.991**	1					
	50%	.898**	.881**	.909**	.935**	.945**	.951**	.976**	.978**	.940**	.935**	1				
	75%	.864**	.852**	.928**	.957**	.971**	.973**	.950**	.936**	.956**	.978**	.896**	1			
P5	25%	.924**	.874**	.944**	.974**	.977**	.976**	.996**	.992**	.979**	.974**	.978**	.950**	1		
	50%	.946**	.880**	.963**	.989**	.976**	.974**	.983**	.992**	.991**	.985**	.956**	.954**	.990**	1	
	75%	.957**	.881**	.977**	.990**	.994**	.981**	.990**	.993**	.995**	.985**	.960**	.950**	.988**	.987**	1

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

P1- *S. betaceum*, P2- *M. paniculata*, P3- *P. emblica*, P4- *V. spinosa*, and P5- *Z. mauritiana*. While 25%, 50%, and 75% stand for different % of shade netting houses having varied light in intensity.

Table 4.7 Pearson correlation between light intensity, recorded in three different shade netting house, and total leaf count.

	Species	P1			P2			P3			P4			P5		
	Shade %	25%	50%	75%	25%	50%	75%	25%	50%	75%	25%	50%	75%	25%	50%	75%
P1	25%	1	-0.63	0.18	0.37	0.534	.714*	0.351	0.514	0.442	0.5	0.635	0.465	0.344	0.384	0.301
	50%		1	-0.31	-.716*	-.831**	-0.472	-0.654	-.794*	-.772*	-.747*	-.707*	-.718*	-.671*	-.749*	-.683*
	75%			1	-0.004	0.146	-0.203	-0.138	0.047	-0.031	-0.017	0.028	-0.014	-0.068	0.083	-0.082
P2	25%				1	.912**	0.422	.898**	.944**	.958**	.965**	.811**	.967**	.997**	.946**	.979**
	50%					1	0.623	.927**	.991**	.972**	.971**	.944**	.958**	.892**	.980**	.929**
	75%						1	0.652	0.621	0.611	0.593	.763*	0.558	0.43	0.514	0.47
P3	25%							1	.950**	.974**	.947**	.880**	.947**	.905**	.944**	.957**
	50%								1	.989**	.993**	.945**	.985**	.931**	.983**	.961**
	75%									1	.985**	.903**	.979**	.953**	.976**	.979**
P4	25%										1	.930**	.996**	.959**	.977**	.974**
	50%											1	.915**	.795*	.904**	.844**
	75%												1	.962**	.972**	.978**
P5	25%													1	.933**	.979**
	50%														1	.972**
	75%															1

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

P1- *S. betaceum*, P2- *M. paniculata*, P3- *P. emblica*, P4- *V. spinosa*, and P5- *Z. mauritiana*. While 25%, 50%, and 75% stand for different % of shade netting houses having varied light in intensity.

Table 4.8 Pearson correlation between light intensity, recorded in three different shade netting houses, and plant leaf area.

	Species	P1			P2			P3			P4			P5		
	Shade %	25%	50%	75%	25%	50%	75%	25%	50%	75%	25%	50%	75%	25%	50%	75%
P1	25%	1														
	50%	.338	1													
	75%	.809**	.814**	1												
P2	25%	.919**	.444	.842**	1											
	50%	.949**	.473	.876**	.904**	1										
	75%	.769*	.782*	.956**	.867**	.845**	1									
P3	25%	.652	.455	.627	.394	.576	.481	1								
	50%	.934**	.536	.888**	.919**	.897**	.859**	.616	1							
	75%	.708*	.435	.723*	.885**	.658	.821**	.211	.779*	1						
P4	25%	.943**	.419	.830**	.972**	.876**	.818**	.522	.928**	.861**	1					
	50%	.971**	.404	.822**	.957**	.931**	.824**	.578	.923**	.771*	.967**	1				
	75%	.950**	.354	.762*	.807**	.858**	.683*	.813**	.867**	.585	.889**	.927**	1			
P5	25%	.740*	.814**	.949**	.823**	.749*	.944**	.589	.854**	.822**	.827**	.783*	.715*	1		
	50%	.811**	.660	.899**	.718*	.911**	.846**	.693*	.836**	.491	.691*	.769*	.754*	.755*	1	
	75%	.821**	.715*	.953**	.921**	.908**	.970**	.425	.885**	.801**	.867**	.870**	.713*	.893**	.853**	1

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

P1- *S. betaceum*, P2- *M. paniculata*, P3- *P. emblica*, P4- *V. spinosa*, and P5- *Z. mauritiana*. While 25%, 50%, and 75% stand for different % of shade netting houses having varied light in intensity.

Comparison analysis using Two-Way ANOVA revealed the effects of net shadings on plant growth parameters (Table 4.9). Significant difference was observed for *S. betaceum* (F =14.64, p = 0.00), and *P. emblica* (F =23.45, p = 0.00). However, it was found insignificant for *M. paniculata* (F = 2.33, p = 0.12), *V. spinosa* (F = 0.48, p = 0.63), and *Z. mauritiana* (F = 0.378, p = 0.69) in terms of plant height. Only *S. betaceum* (F = 18.22, p = 0.00) and *M. paniculata* (F = 3.94, p = 0.03) showed a significant difference in leaf count. In case of leaf area, *P. emblica* (F = 14.22, p = 0.00) and *S. betaceum* (F = 25.91, p = 0.00) displayed the significant difference under different shade conditions.

Additionally, Table 4.10 showed the Pearson's correlation between the microclimatic conditions and relative growth rate in terms of height and leaf area. It reveals that humidity plays the negative impact in plant height and temperature in leaf area of the plant species under investigation with r value -0.65 and -0.61, respectively at 99.95% of confidence level. However, it's important to consider that correlation does not necessarily imply causation. Other factors might also be influencing plant height, and further research is required to establish the exact mechanisms by which humidity affects plant growth. Overall, the information suggests that maintaining appropriate humidity levels.

Table 4.9 Comparison analysis on the effects recorded under three different shade netting houses on plant growth parameters (height, total leaf count, and leaf area) among species using Two-Way ANOVA

	Height			Total leaf count			Leaf area		
Dependent Variable	Mean Square	F	Sig.	Mean Square	F	Sig.	Mean Square	F	Sig.
Microcos paniculata	173.97	2.33	0.119	866.24	3.94	0.033	13.13	2.98	0.07
Phyllanthus emblica	4541.69	23.45	0	42.26	0.73	0.49	950.07	14.22	0
Solanum betaceum	108.17	14.64	0	12.47	18.22	0	1004.59	25.91	0
Vangueria spinosa	36.56	0.48	0.625	28.99	1.41	0.264	447.92	3.21	0.058
Ziziphus mauritiana	74.02	0.38	0.689	501.22	2.55	0.099	20.71	1.16	0.332

Table 4.10 Pearson correlation between micro-climatic conditions, and plant relative growth

	Light intensity	Temperature	Humidity	Soil temperature	RGRH	RGRA
Light intensity	1					
Temperature	.723**	1				
Humidity	-.735**	-.663*	1			
Soil temperature	-.180	.319	.091	1		
RGRH	.493	.485	-.654*	.339	1	
RGRA	-.289	-.607*	.014	-.461	-.173	1

*. Correlation is significant at the 0.05 level (2-tailed).

4.3.6 Pigment content

The estimated levels of chlorophyll a (Chl a), chlorophyll b (Chl b), total chlorophyll, and total carotenoid in immature (leaves collected after 10 days of germination) and mature leaves (at 90 days after germination) of various fruit species cultivated under different shading conditions (25%, 50%, and 75% shade) are given in Table 4.11. Fig. 4.8 represents the graphical representation of chlorophyll and carotenoid content. For immature leaves, *Vangueria spinosa* exhibited the highest values for Chl a (101.82 ± 0.18), Chl b (44.27 ± 1.00), total chlorophyll (146.06 ± 1.12), and total carotenoids (22.87 ± 0.67) among the fruit species. *Phyllanthus emblica* had the second-highest values for Chl b having 26.63 ± 0.58, while *Ziziphus mauritiana* had the second-highest value for Chl a (55.14 ± 0.60) and total Chl (73.73 ± 1.69), and *Microcos paniculata* with 14.43 ± 0.20 had the second-highest value for carotenoids. *Solanum betaceum* demonstrated the lowest values for all the measured parameters among the fruit species. The trend of total chlorophyll content in immature leaves represents as *Vangueria spinosa > Ziziphus mauritiana> Microcos paniculata> Phyllanthus emblica> Solanum betaceum*. While for carotenoid content represents as *Vangueria spinosa > Microcos paniculata > Ziziphus mauritiana> Phyllanthus emblica> Solanum betaceum*

For mature leaves under 25% shade, *M. paniculata* displayed the highest Chl a with 44.28 ± 0.11 and total chlorophyll content with 66.25 ± 0.11 while, the highest Chl b (29.63 ± 0.16) was observed in *Vangueria spinosa* and total carotenoids in *S. betaceum* having 10.93 ± 0.13. The lowest Chl a content was recorded in *S. betaceum* exhibiting 8.28 ± 0.34 and *P. emblica* had the lowest value of Chl b, total chl and total carotenoid having 5.41 ± 0.56, 14.11 ± 0.40 and 3.48 ± 0.41, respectively. Under 50% shade for mature leaves, *M. paniculata* displayed the highest Chl a (42.84 ± 0.13), while Chl b (41.19 ± 0.48.), and total chlorophyll content (80.22 ± 0.35) observed highest in *P. emblica*. However, total carotenoid (8.57 ±0.16) observed highest in *V. spinosa*. *S. betaceum* had the lowest value for Chl a, and total carotenoid having 14.79 ± 0.19 and 3.54 ± 0.14, respectively. While *V. spinosa* had the lowest Chl b content and total chlorophyll with 10.61 ± 0.30 and 28.54 ± 0.25, respectively. Under 75% shade, *V. spinosa* exhibited the highest Chl a content (109.06 ± 0.14), Chl b content (32.14 ± 0.21), total chlorophyll (91.72 ± 1.05), and total carotenoid (21.09 ± 0.19), while *S. betaceum* displayed the lowest Chl a, total chlorophyll, and total carotenoids with the value 19.06 ± 0.19, 51.24 ± 0.21 and 6.15 ± 0.18. However, lowest Chl b was observed in *P. emblica* (12.47 ± 0.30).

Table 4.11 Chlorophyll (a, b and Total) and carotenoid (total carotenoids) content in immature and mature leaves of different fruit species under varying levels of shading (25%, 50%, and 75% shade)

Leaves	Parameters		*Microcos paniculata*	*Phyllanthus emblica*	*Solanum betaceum*	*Ziziphus mauritiana*	*Vangueria spinosa*
Immature leaves	Chl a		47.45 ± 0.59	42.78 ± 0.68	21.29 ± 0.28	55.14 ± 0.60	101.82 ± 0.18
	Chl b		18.63 ± 1.12	26.63 ± 0.58	3.22 ± 0.42	18.6 ± 1.10	44.27 ± 1.00
	Total chl		66.06 ± 0.71	69.39 ± 0.78	24.50 ± 0.60	73.73 ± 1.69	146.06 ± 1.12
	Total carotenoid		14.43 ± 0.20	10.16 ± 0.20	5.85 ± 0.25	11.30 ± 0.18	22.87 ± 0.67
Mature leaves	Chl a	25%	44.28 ± 0.11	8.70 ± 0.26	8.28 ± 0.34	26.58 ± 0.32	24.53 ± 0.16
		50%	42.84 ± 0.13	39.06 ± 0.19	14.79 ± 0.19	35.65 ± 0.10	17.94 ± 0.33
		75%	44.81 ± 0.09	41.36 ± 0.31	19.06 ± 0.19	55.68 ± 0.42	109.06 ± 0.14
	Chl b	25%	21.99 ± 0.20	5.41 ± 0.56	15.26 ± 0.61	11.13 ± 0.78	29.63 ± 0.16
		50%	24.50 ± 0.19	41.19 ± 0.48	13.88 ± 0.17	24.61 ± 0.13	10.61 ± 0.30
		75%	19.53 ± 0.51	12.47 ± 0.30	32.19 ± 0.21	16.25 ± 0.49	---
	Total chl	25%	66.25 ± 0.11	14.11 ± 0.40	36.86 ± 0.10	37.70 ± 0.49	54.14 ± 0.32
		50%	67.33 ± 0.23	80.22 ± 0.35	28.65 ± 0.24	60.24 ± 0.23	28.54 ± 0.25
		75%	64.32 ± 0.43	53.82 ± 0.36	51.24 ± 0.21	71.92 ± 0.20	91.72 ± 1.05
	Total carotenoid	25%	8.59 ± 0.21	3.48 ± 0.41	10.93 ± 0.13	8.65 ± 0.25	4.55 ± 0.16
		50%	8.57 ± 0.16	4.61 ± 0.05	3.54 ± 0.14	6.07 ± 0.09	4.73 ± 0.13
		75%	8.52 ± 0.34	9.81 ± 0.08	6.15 ± 0.18	9.33 ± 0.28	21.09 ± 0.19

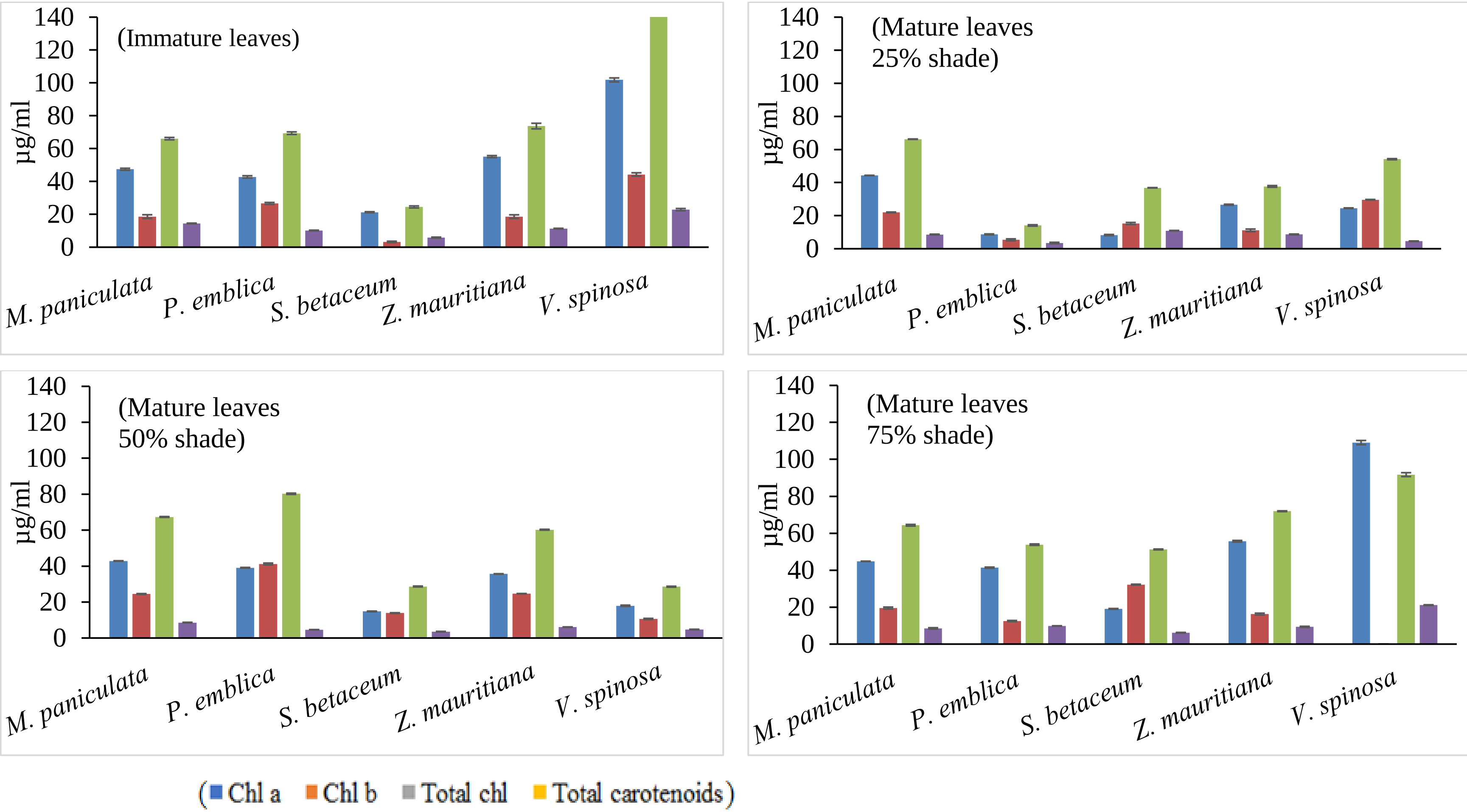

Fig. 4.8 Chlorophyll and carotenoid content found in immature leaves and mature leaves under 25% shade,50% shade and 75% shade.

4.3.7 Photosynthesis rate using IRGA.

The photosynthetic rate of wild edible fruit plants cultivated under three distinct shade netting houses (25%, 50%, and 75%) was assessed using an Infrared Gas Analyzer (IRGA). Among the fruit species, *P. emblica* exhibited the highest photosynthetic rate having 7.60 µmole CO_2 m^2sec^{-1} under 25% shade, whereas *M. paniculata* showed the highest rate (5.69 µmole CO_2 m^2sec^{-1}) under 50% shade. Under 75% shade, *Z. mauritiana* demonstrated the highest photosynthetic rate with 9.00 µmole CO_2 m^2sec^{-1}. *S. betaceum* recorded lowest photosynthetic rate having 3.80 and 4.08 µmole CO_2 $m^2sec^{-}1$, respectively in 25% and 75% shade. Detailed information regarding the photosynthetic rate of each fruit species is given in Table 4.12 and Fig. 4.9. The findings reveal variations in the photosynthesis rate (PR) across different fruit species under the various net shading houses. Notably, *P. emblica* and *Z. mauritiana* displayed fluctuations in PR, indicating that their photosynthetic activity is influenced by changes in light intensity. Conversely, *M. paniculata*, *S. betaceum*, and *V. spinosa* exhibited consistent PR values, suggesting that light intensity may have a minimal impact on their photosynthetic activity. Overall, these outcomes underscore the role of light intensity in modulating the PR of specific fruit species. Table 4.13 presents the correlation analysis between the photosynthesis rate (PR) and pigment contents. The results indicate that no significant correlation was found between the PR and the pigment contents overall. However, a significant positive correlation was observed between chlorophyll a (Chl a) and both total chlorophyll and total carotenoids. The correlation coefficient between Chl a and total chlorophyll was 0.835, and the correlation coefficient between Chl a and total carotenoids was 0.820. These correlations were statistically significant at a 99.9% confidence level.

Table 4.12 Photosynthesis rate (PR) recorded in studied wild edible fruits growing under three shade netting houses (25%, 50%, and 75%)

	Photosynthesis rate (µmole CO_2 $m^2 sec^{-1}$)		
Fruits	PR (25%)	PR (50%)	PR (75%)
Microcos paniculata	7.02 ± 0.15	5.69 ± 0.34	5.66 ± 0.24
Phyllanthus emblica	7.60 ± 0.31	2.73 ± 0.15	5.53 ± 0.75
Solanum betaceum	3.80 ± 0.23	3.33 ± 0.05	4.08 ± 0.13
Vangueria spinosa	3.94 ± 0.03	3.21 ± 0.17	4.37 ± 0.06
Ziziphus mauritiana	4.46 ± 0.21	5.26 ± 0.34	9.00 ± 0.79

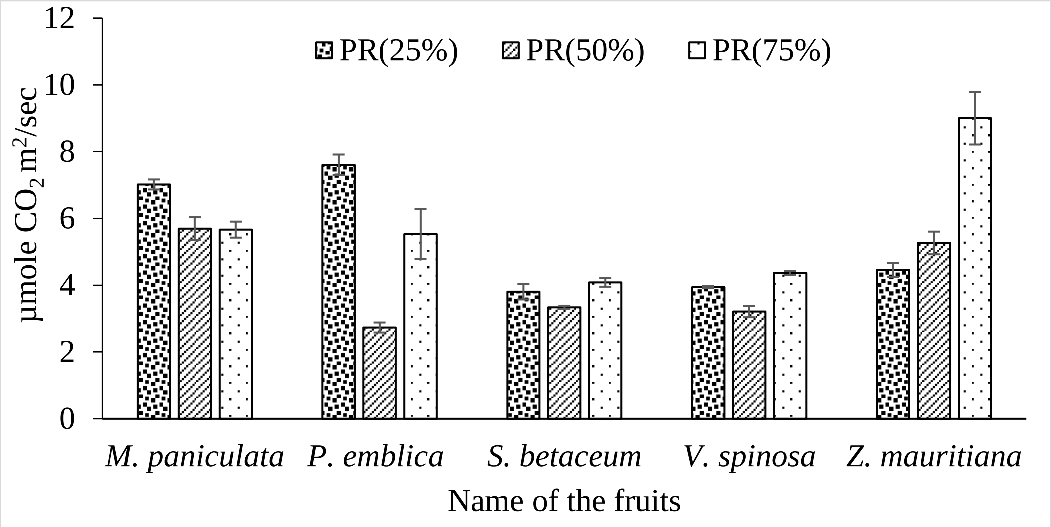

Fig. 4.9 Photosynthesis rate (PR) under three shade netting houses (25%, 50%, and 75% shade)

Table 4.13 Correlation between photosynthesis rate (PR) and pigment content

	PR	Chl_a	Chl_b	Total_chl	Total_carotenoids
PR	1				
Chl_a	.193	1			
Chl_b	-.255	-.235	1		
Total_chl	.089	.835**	.315	1	
Total_carotenoids	.095	.820**	-.473	.580	1

**. Correlation is significant at the 0.01 level (2-tailed).

4.4 DISCUSSION

4.4.1 Climatic measurements

The climatic conditions including light intensity, air temperature, humidity, and soil temperature were measured during the period of the study. The data shows spatial and temporal variations in light intensity across different shade percentages. It is notable that light intensity was generally higher in September and October compared to August months. This may be attributed to seasonal variations, shade nets or other factors that attenuate light penetration through the shade netting. Air temperature determines the thermal conditions inside the shade netting house. The findings indicate that air temperature was largely constant during the research period, with very minor changes being noted. This indicates that the fruit species experienced a consistent thermal environment for during their growth and development. The recorded humidity levels exhibited some variations but generally remained within the range between 72.52% - 85.96%. This suggests that the moisture conditions inside the shade netting house were relatively favourable for the fruit species to grow. However, specific humidity requirements for optimal growth may vary among different fruit species. Soil temperature provides insights into the thermal conditions in the growing medium. The data shows a constant soil temperature throughout the study period, indicating a stable thermal environment for the plant roots. Stable soil temperature is essential for root development and nutrient uptake by the plants. Additionally, the study revealed a negative correlation between temperature and humidity. As temperature increases, relative humidity decreases, resulting in drier air. This condition promotes plant growth through enhanced evaporation.

The climatic data collected in this experiment revealed that the primary distinction in the microclimate among the shade nets was the light intensity. This finding is consistent with a previous study conducted on eggplant [14]. In contrast to our study, previous research has demonstrated significant differences in greenhouse air temperature due to shading [20,21]. Several studies have examined the effects of shade netting on environmental conditions and plant growth. For instance, a study investigated the effects of nursery shading on the growth, chlorophyll content, and PSII of "Lane Late" navel orange seedlings [22]. Another study explored the effects of three shading nets on the growth and fruiting of red-fleshed 'Shih Huo Chuan' pitaya [12]. Additionally, effects of photoselective netting on root growth and development of young grafted orange trees under semi-arid climate was investigated in a separate study [13].

4.4.2 Germination and survivability

Throughout the study, a comprehensive investigation was conducted to assess the germination and survivability of various fruit species. Germination, which denotes the process of seed sprouting and seedling development, was carefully observed, and the collected data provided valuable insights into the germination period and percentage for each fruit species. The results demonstrated notable variations in the germination period among the different fruit species. For instance, *Microcos paniculata*, *P. emblica, Rhus semialata* and *Solanum betaceum* exhibited relatively shorter germination periods, ranging from 14 to 17 days, 7 to 9 days, 10 to 20 days, and 10 to 12 days, respectively. Conversely, *Vangueria spinosa* and *Ziziphus mauritiana* showcased longer germination periods, spanning from 43 to 51 days and 23 to 32 days, respectively. It is worth noting that *E. floribundus* did not germinate during the study period, potentially due to the hardness of its seed coat. To facilitate germination, the seeds were soaked in water for 24 hours, as previous studies have shown that soaking seeds in water at room temperature helps soften the seed coat, remove inhibitors, reduce germination time, and increase germination percentage [24]. Additionally, seed longevity is primarily influenced by the environment and the presence of endosperm, with differences in seed coat thickness also affecting seed longevity [25,26].

The germination percentage, which indicates the proportion of successfully sprouted seeds, was also determined for each species. Encouragingly, most fruit species exhibited high germination rate, with *M. paniculata*, *S. betaceum*, and *Z. mauritiana* achieving a full 100% germination rate. On the other hand, survivability, which refers to the ability of germinated seedlings to establish themselves as healthy plants, displayed variations across different fruit species. Species such as *M. paniculata*, *P. emblica*, *S. betaceum*, and *Z. mauritiana* demonstrated high survivability rates. These species exhibited healthy growth and development, underscoring their adaptability and successful establishment within the study's conditions. However, it is noteworthy that *R. semialata* exhibited a significantly lower survivability rate. This implies that this species encountered challenges or unfavourable conditions that hindered its growth and survival. Further investigation into the specific factors influencing the low survivability of *R. semialata* would be valuable for understanding its requirements and optimizing its cultivation practices. Moreover, exploring different pre-treatment techniques could potentially contribute to enhancing the germination process for improved outcomes [15,27,28]. Studies have shown that good-quality seedlings with greater height and root collar diameter have a higher chance of survival in natural conditions [29]. The proximity of nearest neighbours also influences seedling survival [30]. Furthermore, Hegarty (1978) reported successful seedling growth at water potentials that were lower than those required for germination [31].

4.4.3 Root-shoot ratio

For the examined fruit species, it is evident that the root-shoot ratio is highest at the 10day after germination and gradually decreases as the plants grow over a period of 90 days under shade conditions. This pattern signifies that during the initial stage of germination and early growth, a larger proportion of biomass is allocated to the root system compared to the above-ground shoot. Such allocation pattern is commonly observed as the root system establishes and matures to support plant growth. Studies [32–34] have shown that the proliferation of roots at the surface soil is likely linked to increased availability of soil water and nutrients. Moreover, the root-shoot ratio demonstrates a general decline with increasing shade percentage for the fruit species under investigation. This implies that under higher shade conditions, such as 75% shade, the plants allocate a relatively smaller portion of their biomass to the root system in comparison to the above-ground shoot. Conversely, in lower shade conditions like 25% shade, a greater proportion of biomass is directed towards root growth. This trend can be attributed to plants' adaptive responses to varying light availability. In low light conditions, plants allocate more resources to root growth, facilitating improved nutrient and water absorption from the soil. Conversely, in higher light conditions where greater photosynthetic energy is accessible, plants allocate more resources to shoot growth, thereby promoting enhanced photosynthesis and canopy development. Similar observations have been reported by Cripps (1972) [35] and Smith and Shackleton (1988) [34], that shades reduced root growth and root-to-shoot ratio [35,36]. Consequently, the shade percentage plays a significant role in influencing the root-shoot ratio, exemplifying the plants' resource allocation between roots and shoots in response to light availability. Understanding this relationship is essential for optimizing plant growth and productivity, particularly in controlled environments or when managing shade conditions in agricultural practices. The root-shoot ratio is also one of the basic and very important traits that can assess the overall plant health and complex physiological level of analysed genotypes [37].

4.4.4 Total biomass

The investigation of total biomass is essential to assess plant growth and productivity, encompassing both above-ground and below-ground components. Among the examined fruit species, significant differences in total biomass were observed across the various shade houses. *Microcos paniculata* demonstrated the highest total biomass in the 25% shade house (2.81 ± 0.73 g), followed by a decline in biomass within the 50% shade house (1.00 ± 0.34 g) and the 75% shade house (1.25 ± 0.18 g). These findings suggest that *Microcos paniculata* thrives under lower shade conditions, optimizing its biomass production. Similarly, *Phyllanthus emblica* exhibited the highest total biomass in the 75% shade house (5.61 ± 0.84 g), followed by the 25% shade house (5.38 ± 1.19 g), and the lowest biomass in the 50% shade house (1.35 ± 0.41 g), indicating its preference for low light conditions. *Solanum betaceum* displayed a decreasing trend in total biomass as shade percentage increased. The highest biomass was observed in the 25% shade house (3.25 ± 0.42 g), followed by the 50% shade house (2.07 ± 0.36 g), and the lowest biomass in the 75% shade house (1.65 ± 0.64 g). This suggests that *Solanum betaceum* achieves optimal biomass production under lower shade conditions. *Vangueria spinosa* exhibit the highest total biomass in the 25% shade house (24.13 ± 1.02 g), followed by the 75% shade house (18.41 ± 1.50 g), and the lowest biomass in the 50% shade house (5.18 ± 0.84 g), indicating its ability to thrive under both lower and higher shade conditions, with a preference for moderate shade. *Ziziphus mauritiana* exhibited the highest total biomass in the 50% shade house (11.74 ± 0.88 g), followed by the 25% shade house (10.90 ± 3.90 g), and the lowest biomass in the 75% shade house (2.60 ± 0.58 g), suggesting its favourable performance under moderate shade conditions. The data clearly demonstrates the influence of shade conditions on the total biomass of the examined fruit species, highlighting their species-specific responses to light availability. These findings highlight the significance of optimizing shade conditions to achieve optimal growth and productivity for each fruit species. Further investigations are warranted to explore into the underlying physiological and ecological mechanisms that drive the observed biomass patterns. Notably, previous studies have examined the effect of shade levels on biomass production in cactus, reporting similar findings of higher biomass in plants subjected to 25% and 50% shade levels compared to those in 75% shade. This aligns with the findings for the fruit trees *Microcos paniculata*, *Solanum betaceum*, and *Vangueria spinosa* in the present study [38]. The interrelationship between plant biomass, productivity, and crop growth and development further highlights the relevance of these findings [39–42].

4.4.5 Correlation between climatic measures, root-shoot ratio, and biomass

The result of correlation analysis given in Table 4.5 reveals the relationships between different variables, including climatic measures, root-shoot ratio, and biomass. First, the significant negative correlation (-0.66) between temperature and humidity suggests that these two variables have an inverse relationship. As temperature increases, humidity tends to decrease, indicating that higher temperatures are associated with drier air [43]. This finding is consistent with the principle of evaporation, which states that an increase temperature leads to greater evaporation and reduced moisture content in the air [44]. Secondly, the significant positive correlation (0.71) observed between light intensity and total biomass indicates a direct relationship between these variables. It has been found that higher light intensity corresponds with a higher biomass, indicating that increased light availability promotes greater root-shoot development. This relationship is consistent with the adaptive responses of plants to optimize nutrient uptake and enhance photosynthesis under favourable light conditions [39,41].

These correlations provide valuable insights into the interactions between climatic factors, and biomass. Understanding these relationships is essential for better understanding the physiological responses of plants to environmental conditions and optimizing their growth and productivity. However, no significant correlation was observed between biomass and the other variables studied.

4.4.6 Growth rate parameters

During the 90-day period of growth analysis of wild edible fruits, notable variations were observed in terms of height, total leaf count, and leaf area. These variations were analysed under three different shade conditions: 25%, 50%, and 75% shade netting houses.

4.4.6.1 Microcos paniculata

In the 25% shade condition, the species *Microcos paniculata* demonstrated the highest plant height, with an increase from 9.30 cm at day 10 to 41.57 cm at day 90. The total leaf count also exhibited a significant increase, ranging from 5.67 leaves at day 10 to 69.33 leaves at day 90. The leaf area gradually increased over time, ranging from 7.16 to 12.73 cm^2. The relative growth rate analysis revealed a notable relative growth rate, with the height increasing from 2.04 to 3.36 cm cm^{-1} mo^{-1}over the observed period. Additionally, the relative leaf area values ranged from 0.05 to -0.01 cm^2 cm^{-2} mo^{-1}, indicating slight variations in leaf area over time.

Under the 50% shade condition, *Microcos paniculata* displayed slightly lower growth compared to the 25% shade condition. The plant height ranged from 7.33 cm to 28.37

cm, and the total leaf count increased from 5.67 leaves to 22.67 leaves. The leaf area showed some fluctuations but generally increased, ranging from 6.07 to 12.60. The relative growth rate analysis indicated a relatively lower growth rate, with height values ranging from 0.01 to 0.04 cm cm^{-1} mo^{-1}, indicating minimal growth or fluctuations in height. Similarly, the relative leaf area values ranged from 0.03 to -0.01 cm^2 cm^{-2} mo^{-1}, showing minor fluctuations.

In the 75% shade condition, *Microcos paniculata* exhibited the lowest growth compared to the other shade conditions. The plant height ranged from 8.70 cm to 24.60 cm, and the total leaf count increased from 6.00 leaves to 15.33 leaves. The leaf area displayed an increasing trend, starting from 7.08 and reaching 14.33. Based on the relative growth rate analysis, the plants showed even lower relative growth rates, with height values ranging from 0.00 to 0.02 cm cm^{-1} mo^{-1}, suggesting limited or negligible growth. The relative leaf area values ranged from 0.05 to -0.01 cm^2 cm^{-2} mo^{-1}, indicating slight changes over time.

Overall, the plants exhibited noticeable growth in height across all shade conditions, with the most significant growth observed in the 25% shade condition. However, the leaf area values were relatively small across all shade conditions, suggesting a relatively stable or minimal growth pattern.

4.4.6.2 Phyllanthus emblica

Under 25% shade, the fruit species *P. emblica* showed an increasing trend in both height and total leaf count throughout the observed period. The highest values for height and leaf count were recorded on day 90, indicating continuous growth. However, there were no significant differences observed in leaf area, suggesting that the expansion of leaf area did not vary significantly over time. The leaf area *P. emblica* fruits increased steadily over time, ranging from 10.81 to 23.78 cm^2. This indicates a gradual expansion of the leaf surface area during the growth period. The relative growth rate in height for *P. emblica* fruits ranged from 2.65 cm cm^{-1} mo^{-1} on day 10 to 3.53 cm^2 cm^{-2} mo^{-1} on day 90. This indicates a notable increase in height over time, suggesting active growth and development of the plants. On the other hand, the relative growth rate in leaf area ranged from 0.03 cm cm^{-1} mo^{-1} on day 10 to 0.01 cm^2

cm^{-2} mo^{-1} on day 90, suggesting a relatively slower rate of leaf area expansion compared to height growth.

In the 50% shade condition, *P. emblica* demonstrated a consistent growth pattern characterized by a gradual increase in both height and total leaf count over the duration of the study. The measurements of leaf area ranged from 18.72 cm^2 on day 10 to 54.03 cm^2 on day 90, indicating a progressive expansion of the leaf surface. The relative growth rate in height for *P. emblica* exhibited a range of values, starting from 0.08 cm cm^{-1} mo^{-1}on day 10 and gradually decreasing to 0.00 cm cm^{-1} mo^{-1}on day 90. These findings suggest that the rate of height growth progressively slowed down over time, eventually reaching a relatively stable level. Similarly, the relative growth rate in leaf area displayed variations, with values ranging from 0.09 cm^2 cm^{-2} mo^{-1} on day 10 to 0.02 cm^2 cm^{-2} mo^{-1} on day 90. These observations indicate that the rate of leaf area expansion was comparatively higher in the early stages of the study and gradually decreased throughout the observation period.

Under the 75% shade condition, *P. emblica* exhibited a distinct growth pattern compared to the other two shade conditions. The height of the plants and the total leaf count showed an increasing trend over the 90-day observation period, reaching their highest values on day 90. The leaf area measurements ranged from 10.39 cm^2 on day 10 to 23.89 cm^2 on day 90, indicating a progressive increase in the surface area of the leaves. In terms of relative growth rate, the height of *P. emblica* showed variations over time ranging from 0.04 cm cm^{-1} mo^{-1}on day 10 to 0.00 cm cm^{-1} mo^{-1}on day 90, indicating that the rate of height growth gradually decreased and eventually reached a relatively stable level by the end of the study. Similarly, the relative growth rate in leaf area exhibited fluctuations throughout the observation period. The values ranged from 0.03 cm^2 cm^{-2} mo^{-1}on day 10 to 0.02 cm^2 cm^{-2} mo^{-1}on day 90, suggesting slight variations in the rate of leaf area expansion.

In summary, the growth of *P. emblica* fruits was influenced by shade conditions, with optimal growth observed under 50% shade, followed by 25% shade, while 75% shade resulted in comparatively lower growth.

4.4.6.3 Solanum betaceum

Under the 25% shade condition, the plant species *Solanum betaceum* demonstrated a consistent growth pattern characterized by a gradual increase in both height and total leaf count over the observed period. Following transplantation, the leaf area exhibited a steady growth, ranging from 2.59 cm^2 on day 10 to 14.86 cm^2 on day 90. The relative growth rate in height (RGRH in cm cm^{-1} mo^{-1}) showed a relatively stable pattern, ranging from 1.89 on day 10 to 2.15 on day 90, indicating a moderate and consistent growth rate in height throughout the observation period. In contrast, the relative growth rate in leaf area (RGRA in cm^2 cm^{-2} mo^{-1}) displayed variations, ranging from 0.04 on day 10 to 0.02 on day 90. These observations suggest a modest increase in leaf area initially, followed by a relatively stable or slower growth rate.

When subjected to 50% shade, *Solanum betaceum* displayed similar growth patterns, with the height and total leaf count increasing steadily over time. The leaf area increased from 7.73 square units at day 10 to 30.48 square units at day 90. The RGRH (cm cm^{-1} mo^{-1})values were generally low, ranging from 0.03 at day 10 to -0.01 at day 90. This suggests minimal or negligible growth in height over time. However, the RGRA (cm^2 cm^{-2} mo^{-1}) values were higher compared to the other two conditions, ranging from 0.20 at day 10 to 0.00 at day 90. This indicates significant growth in leaf area initially, but the growth rate decreased over time and eventually reached near zero.

Under the 75% shade condition, the plant species *Solanum betaceum* displayed similar growth patterns to the other shade conditions, characterized by a gradual increase in height and total leaf count over time. The leaf area measurements ranged from 7.73 cm^2 on day 10 to 30.48 cm^2 on day 90, indicating a progressive expansion of the leaf surface. The relative growth rate in height (RGRH in cm cm^{-1} mo^{-1}) remained relatively low throughout the study period, ranging from 0.02 on day 80 to -0.01 on day 90. These findings suggest limited or no significant growth in height during the observation period. Furthermore, the relative growth rate in leaf area (RGRA in cm^2 cm^{-2} mo^{-1}) exhibited lower values compared to the 50% shade condition, ranging from

0.15 on day 10 to 0.01 on day 90. This indicates a moderate increase in leaf area initially, followed by a gradual decrease in the growth rate.

These findings indicate that *Solanum betaceum* has the capacity to adapt to varying shade conditions and maintain growth and development. The observed growth patterns reflect the versatility and resilience of *Solanum betaceum*, enabling it to thrive under different light intensities. Understanding these adaptive properties is crucial for effective shade management and optimizing the growth and productivity of *Solanum betaceum* plants.

4.4.6.4 Vangueria spinosa

In the 25% shade condition, *Vangueria spinosa* demonstrated a gradual increase in height, from 8.02 cm on day 10 to 36.60 cm on day 90. The total leaf count also steadily increased from 3.60 on day 10 to 19.33 on day 90. The leaf area exhibited a similar pattern, starting at 12.27 cm^2 on day 10 and reaching 37.67 cm^2 on day 90. The relative growth rate in height (RGRH in $cm\ cm^{-1}\ mo^{-1}$) showed a consistent and significant growth, ranging from 1.89 on day 10 to 3.25 on day 90. However, the relative growth rate in leaf area (RGRA in $cm^2\ cm^{-2}\ mo^{-1}$) displayed variations, ranging from 0.03 on day 10 to 0.00 on day 90, indicating a modest increase initially followed by a stable or slower growth rate.

Under the 50% shade condition, *Vangueria spinosa* exhibited height measurements ranging from 9.96 cm to 24.43 cm over the 90-day period. The total leaf count increased from 2.80 to 10.33, and the leaf area steadily increased from 17.61 cm^2 on day 10 to 35.22 cm^2 on day 90. The relative growth rate in height (RGRH in $cm\ cm^{-1}\ mo^{-1}$) remained relatively low, ranging from 0.03 on day 10 to 0.01 on day 90, indicating minimal or negligible growth in height. The relative growth rate in leaf area (RGRA in $cm^2\ cm^{-2}\ mo^{-1}$) exhibited fluctuations, ranging from 0.06 on day 10 to 0.00 on day 90, indicating varying growth rates with initial growth followed by a decrease or no significant change in leaf area.

In the 75% shade condition, *Vangueria spinosa* exhibited height measurements ranging from 10.34 cm to 40.57 cm. The total leaf count ranged from 4.00 to 16.67.

The leaf area showed the highest growth, starting at 18.44 cm^2 on day 10 and reaching 65.58 cm^2 on day 90. The relative growth rate in height (RGRH in cm cm^{-1} mo^{-1}) exhibited slight fluctuations, ranging from 0.04 on day 10 to 0.02 on day 90, indicating limited or slower growth compared to the 25% shade condition. The relative growth rate in leaf area (RGRA in cm^2 cm^{-2} mo^{-1}) was relatively higher, ranging from 0.07 on day 10 to 0.00 on day 90, suggesting a more pronounced increase initially followed by a decrease or stable growth rate over time.

These observations indicate that *Vangueria spinosa* is an adaptable and resilient plant species, showing consistent growth in height, leaf count, and leaf area over the 90-day period. The plant exhibited the highest growth rates and optimal performance in the 75% shade condition, indicating a preference for moderate shade levels.

4.4.6.5 Ziziphus mauritiana

In the 25% shade condition, *Ziziphus mauritiana* exhibited steady growth in height and total leaf count throughout the 90-day period. The leaf area gradually increased from 5.56 cm2 on day 10 to 16.06 cm2 on day 90. The relative growth rate in height (RGRH in cm cm^{-1} mo^{-1}) values increased steadily from 2.17 on day 10 to 3.61 on day 90, indicating significant height growth. The relative growth rate in leaf area (RGRA in cm^2 cm^{-2} mo^{-1}) values varied, ranging from 0.04 on day 10 to 0.01 on day 90, suggesting a modest increase in leaf area initially followed by a relatively stable or slower growth rate.

Under 50% shade, *Z. mauritiana* showed similar growth trends, with gradual increases in height and total leaf count over time. the leaf area varied, starting at 4.15 cm^2 on day 10, peaking at 19.01 cm^2 on day 90, and reaching a low of 10.74 square units on day 50. The relative growth rate in height (RGRH in cm cm^{-1} mo^{-1}) values remained relatively low, indicating minimal or negligible growth in height over time. The relative growth rate in leaf area (RGRA in cm^2 cm^{-2} mo^{-1}) values showed fluctuations, with notable initial growth followed by a decrease or no significant change in leaf area over time.

In the 75% shade condition, *Z. mauritiana* displayed a similar growth pattern, with a steady increase in height and total leaf count over the 90-day period. The leaf area measurements ranged from 4.25 cm^2on day 10 to 19.79 cm^2on day 90. The relative growth rate in height (RGRH in cm cm^{-1} mo^{-1}) values showed fluctuations but remained relatively stable at around 0.02 after day 20. The relative growth rate in leaf area (RGRA in cm^2 cm^{-2} mo^{-1}) values also exhibited fluctuations, but they remained positive and relatively stable throughout the observation period, with slight variations around 0.02.

Based on the growth characteristics, *Ziziphus mauritiana* showed adaptability and resilience under different shade conditions, with steady growth in height, total leaf count, and leaf area. The 25% shade condition resulted in consistent and significant growth, while the 50% and 75% shade conditions exhibited variations in leaf area growth. These findings highlight the plant's ability to adjust to varying light conditions and thrive in different environments.

In general, growth rates of most of the individuals tree species are comparatively conservative overtime and thus increment are found to be remain more or less similar producing almost linear increase in different growth parameters over 90 days (3 months) despite different shade conditions. This finding is accordance with the study conducted in tropical forests of Assam [45].

4.4.6.6 Effect of season changes in relative growth rate

The analysis of the Relative Growth Rate in Height (RGRH in cm cm^{-1} mo^{-1}) in the 25% shade condition reveals distinct variations in growth rates among the five plant species. *S. betaceum*, *M. paniculata*, *P. emblica*, *V. spinosa*, and *Z. mauritiana*, across different seasons. During the monsoon period of July-August, all species exhibited relatively moderate growth rates, ranging from 1.91 to 3.08, indicating a steady but not excessively rapid increase in height. In the August-September period, the growth rates escalated for all species, ranging from 2.08 to 3.36, suggesting a more pronounced growth phase compared to the previous season. The post-monsoon period of September-October witnessed a further rise in growth rates for all species, ranging from 2.15 to 3.61, signifying a continued acceleration in height growth. These findings highlight the seasonal variations in growth rates among the plant species studied under the 25% shade condition, emphasizing the importance of considering seasonality in plant growth research and understanding species-specific responses to seasonal changes.

Under the 50% shade condition, the five plant species displayed varying growth rates across different seasons. During the monsoon period (July-August), all species exhibited relatively low growth rates, ranging from 0.01 to 0.03 cm cm^{-1} mo^{-1}, indicating slow and limited height increase. In the August-September period, most species (*M. paniculata*, *S. pinnata*, *V. spinosa*, and *S. betaceum*) experienced a drop or near-negligible growth rates close to 0 cm cm^{-1} mo^{-1}, indicating minimal or no significant growth in height. By the post-monsoon period (September-October), the growth rates further declined, with some species even exhibiting negative growth rates, suggesting a decrease in height or stagnant growth during this season. The data suggests that the plant species studied under the 50% shade condition experienced limited growth and exhibited varying responses to the changing seasons.

In the 75% shade condition, the growth rates for the different plant species were generally low during the monsoon season (July-August), ranging from 0.01 to 0.03 cm cm^{-1} mo^{-1}. This suggests a slow and limited increase in height during this period. In the August-September period, the growth rates remained relatively stable, with values ranging from 0.01 to 0.02 cm cm^{-1} mo^{-1}, indicating a consistent but modest growth phase. By the post-monsoon period (September-October), the growth rates varied among the different species, with some displaying negative growth rates or stagnant growth, implying a decrease in height or limited growth during this season. Overall, the data suggests that the plant species studied under the 75% shade condition experienced varying growth rates in response to the changing seasons. These findings underscore the importance of shade levels in influencing plant growth and highlight the need for further investigation into the specific environmental factors that influence the growth of these species under the given shade condition.

Based on the analysis of the Relative Growth Rate in Area (RGRA in cm^2 cm^{-2} mo^{-1}) in the 25% shade condition, it is evident that the five plant species, namely *S. betaceum, M. paniculata*, *P. emblica, V. spinosa,* and *Z. mauritiana,* exhibit distinct variations in growth rate across different seasons. During the monsoon period of July-August, all five plant species demonstrated relatively moderate growth rates, ranging from 0.01 to 0.04. This indicates a steady but not excessively rapid increase in area during this season. Subsequently, in the August-September period, the growth rates became more consistent among the species, with values ranging from -0.02 to 0.02. This suggests a stabilization or slight decline in growth rates compared to the previous month. Moving forward to the post-monsoon period of September-October, the growth rates varied among the species, with values ranging from 0 to 0.02. This indicates a mixed response, with some species showing no growth or minimal growth during this season. In summary, the findings demonstrate that the plant species studied under the 25% shade condition exhibit seasonal variations in growth rates. The growth rates were relatively higher during the monsoon season, became more stable or slightly decreased in the following season, and showed a mixed response in the post-monsoon season.

In the 50% shade condition, the five plant species also displayed variations in growth rate during different seasons. During the monsoon period of July-August, the growth rates varied among the species, ranging from -0.01 to 0.03 cm^2 cm^{-2} mo^{-1}. This indicates a mixed response, with some species showing negative growth rates and others showing moderate growth rates during this season. Moving into the August-September period, the growth rates became more consistent among the species, with values ranging from -0.02 to 0.01 cm^2 cm^{-2} mo^{-1}. This suggests a stabilization or slight decrease in growth rates compared to the previous season, with some species exhibiting negligible or minimal growth. By the post-monsoon period of September-October, the growth rates varied among the species, with values ranging from 0 to 0.03 cm^2 cm^{-2} mo^{-1}. This indicates a mixed response, with some species showing no growth or minimal growth, while others showed moderate growth during this season. Overall, in the 50% shade condition, the growth rates were relatively moderate or varied during the monsoon season, became more stable or slightly decreased in the following season, and showed a mixed response in the post-monsoon season.

Similarly, in the 75% shade condition, the five plant species exhibited variations in growth rate during different seasons. During the monsoon period of July-August, all five plant species exhibited relatively higher growth rates, ranging from 0.01 to 0.05 cm^2 cm^{-2} mo^{-1}. This indicates a significant increase in growth, with some species showing more pronounced growth compared to others. Moving into the August-September period, the growth rates became relatively stable for most species, with values close to 0 cm^2 cm^{-2} mo^{-1}. This suggests a period of minimal or no significant growth in area during this season, indicating a possible growth plateau. By the post-monsoon period of September-October, the growth rates varied among the species, with values ranging from 0 to 0.02 cm^2 cm^{-2} mo^{-1}. Some species displayed limited growth, while others showed moderate growth rates during this season. Overall, the plant species studied in the 75% shade condition exhibit seasonal variations in growth rates. The growth rates were relatively high during the monsoon season, became stable or stagnant in the subsequent season, and showed varying degrees of growth in the post-monsoon season.

The analysis of the growth parameters of the studied wild edible fruits highlights the importance of shade management in optimizing their growth. Each species exhibited unique preferences and responses to different shade levels, emphasizing the need for tailored cultivation practices. shade level had positive impact on height, and total leaf count of most of the fruit species such as *P. emblica*, *S. betaceum*, *V. spinosa* and *Z. mauritiana* exhibited positive associations between shade level and height as well as total leaf area. These findings align with a previous study conducted by Dev et al., 2018 [38]. However, *M. paniculata* exhibited a negative impact with increasing shade level, displaying a preference for 25% shade to achieve optimal growth and leaf development. This observation is consistent with the findings of Nguyen et al., 2022, where eggplants demonstrated optimal growth in a shade level of 21% [14]. Furthermore, Incesu et al., 2016 [46] reported that trees grown under 50% and 75% shade exhibited a higher leaf count, which corresponds to the fruit trees of *P. emblica* and *S. betaceum* in the present study, but contrasted with *M. paniculata*, *V. spinosa*, and *Z. mauritiana*. Ozturk and Serdar, 2011[47], Retamales et al., 2008 [48], and Blakey et al., 2016 [49] reported that leaf area were significantly higher in trees grown under shade netting, consistent with the findings of the fruit trees in the present study, except for *M. paniculata*. Additionally, Garcia-Sanchaz et al., 2015 [50] and Zhou et al., 2018 [13] reported that trees grown under 50% shade intensity were taller compared to those grown in open fields, which corresponds to the responses of *P. emblica* and *S. betaceum,* while others exhibited greater height under lower shade levels (25%).

In all the species under investigation, the peak seedlings growth during rainy season (July. – Aug.) could be attributed to the increased availability of nutrients which is aligned with the different tree seedling from different forest type [51,52]. The seasonal fluctuations in the growth response to the light environment constitute a significant determinant of the growth patterns observed in subtropical tree species [51].

4.4.7 Pigment content and photosynthesis rate

4.4.7.1 Pigment content

The pigment content analysis of the plant's leaf samples reveals variation in the levels of chlorophyll a (Chl a), chlorophyll b (Chl b), total chlorophyll, and total carotenoid content in both immature and mature leaves of various fruit species grown under different shading conditions (25%, 50%, and 75% shade). These findings provide important information on the influence of light intensity and shading on the pigment composition of leaves, as well as valuable information regarding the photosynthetic efficiency and overall growth of the plants.

For *Microcos paniculata*, the Chl a and Chl b contents were lower in mature leaves compared to immature leaves in all shading conditions. Additionally, the Total chl and total carotenoids contents also showed a decrease in mature leaves.

Phyllanthus emblica exhibited a significant decrease in Chl a and Chl b contents in mature leaves compared to immature leaves, regardless of the shading condition. The reduction in pigment content was more pronounced in the 50% shading condition. Similarly, the Total chl content in mature leaves was significantly lower, and the total carotenoid content showed a noticeable decrease compared to immature leaves, with a more significant decline in the 75% shading condition.

Solanum betaceum showed a decrease in Chl a and Chl b contents in mature leaves compared to immature leaves. The decrease was more evident in the 75% shading condition. Interestingly, the Total chl content increased in mature leaves compared to immature leaves in the 50% shading condition, but the opposite trend was observed in the 75% shading condition. The total carotenoid content generally decreased in mature leaves.

In the case of *Ziziphus mauritiana*, both Chl a and Chl b contents were lower in mature leaves compared to immature leaves for all shading conditions. The decrease in pigment content was particularly prominent in the 75% shading condition. Similarly, both Total chl and total carotenoid contents were lower in mature leaves compared to immature leaves for all shading conditions.

For *Vangueria spinosa*, the Chl a content was significantly higher in immature leaves compared to mature leaves. However, the Chl b content was not available for the 75% shading condition. Similarly, the Total chl content was significantly higher in immature leaves compared to mature leaves, and the total carotenoid content showed a similar trend, with higher values in immature leaves. This suggests that *V. spinosa* has a greater capacity to capture light energy and utilize it for photosynthesis compared to the mature leaves.

Overall, there is a consistent trend of decreased Chl a and Chl b contents in mature leaves compared to immature leaves across the different plant species. Similarly, there is a variation in the Total chl and total carotenoid contents of mature leaves compared to immature leaves across different species and shading conditions. The extent and direction of these variations depend on the specific species and the level of shading.

The variations in total carotenoid content among the fruit species under different shading levels further highlight their adaptive responses to varying light conditions. Light intensity has a significant impact on carotenoid concentrations, as excessive radiation can generate reactive oxygen species that may lead to photoinhibition if not effectively scavenged by carotenoids [53]. *S. betaceum* consistently exhibits the highest total carotenoid content, suggesting its role in photoprotection and dissipation of light energy under intense light conditions, which aligns with similar observations made by Bergquist et al., 2007 [54]. Conversely, *V. spinosa* consistently displays the lowest total carotenoid content, indicating a potentially different photoprotection strategy or a greater reliance on other mechanisms to cope with excessive light.

Variations in chlorophyll and carotenoid content were observed and provide valuable comprehension into the physiological responses and adaptations of these fruit species to different shading conditions. Light intensity and shading are critical environmental factors that influence plant growth, development, and photosynthetic performance [11,14,55]. The observed variations in pigment composition among the fruit species indicate their ability to modulate light absorption, energy transfer, and photoprotective mechanisms in response to changes in light availability [55]. Overall, the variation in the light intensity caused by different shade nets was probably a major factor affecting the growth and physiological responses.

Chlorophyll serves as a crucial apparatus for light harvesting in plants, enabling photosynthesis to occur. Previous studies have demonstrated that under specific suboptimal light conditions, such as an unoptimized red/blue light ratio, the content of leaf chlorophyll undergoes changes to enhance light absorption [56]. However, in contrast to the present study, various studies on different crop species have reported decreased levels of chlorophyll content under shade treatments, particularly when light levels were low, as observed in purple pak-choi (*Brassica campestris*) [57], soybean [58] and lettuce [59]. The impact of shade netting on chlorophyll content in subtropical fruit trees has also been investigated previously. For instance, Incesu et al., 2016 [46] observed that navel orange seedlings grown under 75% and 50% shade nets exhibited higher chlorophyll content, while it was lower in clear shade nets and unnetted trees, which strongly correlates with the findings of the present study. Similarly, Chang et al., 2016 [12] reported that 75% shade resulted in the highest chlorophyll content, followed by 50% and 25% shade nets. Medina et al., 2002 [60] also observed that chlorophyll a fluorescence was higher in trees subjected to 50% shading intensity compared to unshaded trees. The elevated chlorophyll content in shaded trees is primarily attributed to the reduced canopy temperatures facilitated by shade nets. High ambient and canopy temperatures can adversely affect chlorophyll synthesis in plants [61]. Shade netting creates a favourable environment for the synthesis of photosynthetic enzymes, thereby increasing the chlorophyll content per unit leaf area [62].

Understanding these variations can provide valuable insights for optimizing cultivation practices, such as selecting suitable shading levels or identifying fruit species with higher photosynthetic potential under specific light conditions. Further research can delve into the underlying physiological and molecular mechanisms behind these pigment variations and their implications for plant performance and productivity. Further research can delve into the underlying mechanisms behind these pigment variations, including the regulation of pigment synthesis, pigment-protein interactions, and the influence of light signalling pathways.

4.4.7.2 Photosynthetic rate

The photosynthetic rate of studied fruit species varied when grown in different net shading houses and responses are species specific. Notably, *P. emblica* and *Z. mauritiana* exhibited notable fluctuations in their photosynthesis rate, indicating a strong correlation with varying light intensity levels. The photosynthetic rate of *P. emblica* showed a significant decrease as the shading intensity increased. Under 25% shade, it had a relatively high photosynthetic rate of 7.60 ± 0.31, which dropped drastically to 2.73 ± 0.15 under 50% shade. However, under 75% shade, the photosynthetic rate slightly increased to 5.53 ± 0.75. This indicates that *P. emblica* is more sensitive to higher shading intensities and its photosynthetic capacity is significantly reduced. Meanwhile, *Z. mauritiana* exhibited a unique trend in its photosynthetic response to shading intensity. Its photosynthetic rate increased as the shading intensity increased. Under 25% shade, it had a photosynthetic rate of 4.46 ± 0.21, which increased to 5.26 ± 0.34 under 50% shade. The highest photosynthetic rate of 9.00 ± 0.79 was observed under 75% shade. This suggests that *Z. mauritiana* is well-adapted to higher shading levels and can enhance its photosynthetic activity under more shaded conditions. This highlights the crucial role of light in regulating their photosynthetic activity. In the case of *V. spinosa*, the photosynthetic rate showed a slight decrease with increasing shading intensity. It had a photosynthetic rate of 3.94 ± 0.03 under 25% shade, which decreased to 3.21 ± 0.17 under 50% shade. However, under 75% shade, the photosynthetic rate increased to 4.37 ± 0.06. This indicates that *V. spinosa* is relatively adaptable to different shading conditions, but it shows a preference for lower shading levels. The photosynthetic rate of *M. paniculata* decreased as the shading intensity increased. It had the highest photosynthetic rate under 25% shade (7.02 ± 0.15), which decreased to 5.69 ± 0.34 under 50% shade and further decreased to 5.66 ± 0.24 under 75% shade. This suggests that *M. paniculata* is more efficient in photosynthesis under lower shading conditions. The photosynthetic rate of *S. betaceum* showed a slight decrease as the shading intensity increased. It had a photosynthetic rate of 3.80 ± 0.23 under 25% shade, which was slightly lower than 3.33 ± 0.05 under 50% shade. Under 75% shade, the photosynthetic rate increased to 4.08 ± 0.13. This suggests that *S. betaceum* is relatively tolerant to moderate shading conditions and can maintain its photosynthetic activity.

The use of shade nets, which partially transmit and diffuse radiant light, can play a crucial role in photosynthesis. Shade nets can reduce canopy temperature and evapotranspiration, thereby increasing photosynthetic activity [62]. Studies by Raveh et al., 2003 [63] and Medina et al., 2002 [60] on 'Murcott' tangor and 'Pera' orange trees, respectively, reported a positive effect of shading nets on carbon dioxide concentration and uptake, aligning with the findings for *P. emblica* and *Z. mauritiana*. Similarly, Zhou et al., 2018 [13] found that net photosynthesis was higher in trees grown under shade nets compared to unnetted trees. Incesu et al., 2016 [46] reported that a shading intensity of 75% enhanced photosystem II compared to trees grown under 13% and 20% shade nets, which corresponds to the observed effects on fruit trees such as *S. betaceum*, *V. spinosa*, and *Z. mauritiana*. Likewise, Juntamanee et al. 2013 [64] discovered that mango trees grown under PVC shade nets exhibited higher net photosynthesis compared to their open field counterparts. Additionally, the increased photosynthesis under shade nets has been strongly associated with optimal net CO_2 uptake due to favourable leaf temperature and a low vapor pressure deficit caused by the shade nets [13,64]. Moreover, the observed differences in photosynthesis rates under different shading intensities align with the respective effects of shading on the growth parameters of these fruit species.

4.4.7.3 Relation between pigment content and photosynthetic rate under different shade conditions

By comparing the photosynthesis rates with the pigment content, we can observe the following trends:

For *Microcos paniculata*, it exhibits relatively higher photosynthesis rates in the 25% shading condition compared to the 50% and 75% shading conditions. This aligns with the maintaining of higher chlorophyll a and total chlorophyll content observed in the mature leaves of *M. paniculata* grown in 25% shade. The species' photosynthetic efficiency decreases as shading intensity increases, reflecting its adaptation to moderate light conditions.

Phyllanthus emblica, in contrast, exhibits a higher photosynthesis rate in the 25% shading condition, despite having lower pigment content compared to plants grown under 50% and 75% shade. This suggests that *Phyllanthus emblica* has adapted to efficiently utilize the available light in moderate shading conditions, even with a relatively lower pigment content. The species may possess other physiological mechanisms or adaptations that enable it to optimize photosynthetic activity in lower shade conditions.

Solanum betaceum exhibits a relatively consistent photosynthesis rate (PR) across different shading conditions, with a slightly higher PR observed in the 75% shading condition. This aligns with the pigment content, which also shows slightly higher levels in the 75% shade. The consistent PR and pigment content suggest that *Solanum betaceum* can maintain its photosynthetic activity and efficiency under varying light intensities. The higher pigment content in the 75% shade indicates that the plant may undergo physiological adjustments to enhance light capture and utilization in response to lower light availability.

Similarly with the *S. betaceum*, *Vangueria spinosa* demonstrates a relatively consistent photosynthesis rate (PR) across different shading conditions, with a slightly higher PR observed in the 75% shading condition. This aligns with the pigment content, which also shows slightly higher levels in the 75% shade. These characteristics suggest that *Vangueria spinosa* is capable of efficiently capturing and utilizing light energy, enabling it to thrive in shaded environments. The consistent PR and pigment content indicate the plant's adaptability to low light conditions and its ability to maintain photosynthetic activity for sustained growth and survival. *Vangueria spinosa's* effective light energy utilization contributes to its successful acclimation to shaded habitats and ensures its continued productivity in such environments.

Ziziphus mauritiana exhibits higher photosynthesis rates in the 75% shading condition and a decrease in photosynthesis rates as light intensity increases. This pattern aligns with the pigment content observed in mature leaves. The higher photosynthesis rates in the 75% shading condition suggest that *Ziziphus mauritiana* is adapted to lower light conditions and can efficiently utilize available light for photosynthesis. The decrease in photosynthesis rates with increasing light intensity indicates that *Ziziphus mauritiana* may have reached its optimal photosynthetic capacity under moderate shade and is less efficient in utilizing higher light intensities.

Among all the studied fruits, *Microcos paniculata* had the highest photosynthesis rate in all three shade houses. Interestingly, despite the uneven patterns in pigment content and photosynthetic rates in all the samples, the relative growth in terms of height showed an elevated pattern in the 25% shade condition for all the fruit samples. This implies that moderate shading at 25% can promote better growth in height for these fruit species. Also indicates that factors other than pigment content and photosynthetic rates may play a significant role in determining the growth response to shading conditions in these fruit plants. However, when analysing the data from Table 4.12, no significant correlation was found between leaf pigment content and photosynthesis rates. This suggests that variations in pigment content in different shade levels varied significantly in the photosynthesis rate. The result is in lined with the observation made by Lichtenthaler et al., 2007 [65]. The growth and development of plants are governed by phytohormones and the corresponding signalling molecules. Through an intricate network of phytohormones, plants possess the ability to perceive changes in both the quality and quantity of light received, enabling them to modulate their growth patterns accordingly [66,67].

4.5 CONCLUSION

This chapter focuses on seed germination, survival, and growth of seven wild edible fruit plants under different shade netting percentages (25%, 50%, and 75%). The study provides insights into microclimate conditions within the shade netting house, including variations in light intensity, stable air temperature, favourable humidity levels, and consistent soil temperature. The study also explores germination periods, percentages, and survivability of fruit species after 10 days of germination in open field. The root-shoot allocation pattern and biomass production vary across shade conditions, emphasizing the need for optimizing shade levels for optimal growth. Growth analysis reveals variations in height, leaf count, and leaf area among different fruit species under various shade conditions. The relative growth rate in height and leaf area varied among the different seasons, with moderate growth rates observed during the monsoon period, reduced growth rates in the August-September period, and increased in the post-monsoon period. These findings highlight the influence of seasonal variations on the growth rates of the studied plant species. Pigment content analysis demonstrates the influence of light intensity and shading on the composition of chlorophyll and carotenoids, crucial for photosynthetic efficiency and overall plant growth. Photosynthetic rates vary among species and in response to shading intensities, indicating species-specific adaptations to light conditions. There is no significant correlation between leaf pigment content and photosynthesis rates, suggesting other factors at play in determining photosynthetic efficiency under varying shading conditions.

The findings highlight the importance of optimizing shade levels for optimal growth and productivity, considering the specific preferences of each fruit species. The research sheds light on the physiological responses and adaptations of these plants to light availability, as evidenced by variations in pigment content and photosynthetic rates. However, further investigations are necessary to delve deeper into the underlying mechanisms driving these patterns and to explore additional factors influencing photosynthetic efficiency. Overall, this study contributes to our understanding of the cultivation practices and environmental factors that impact fruit species, offering valuable information for future research and cultivation strategies in this field.

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