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Leaf Mold and Cocopeat based Improvements in Morpho-Biochemical and Photosynthetic Attributes of Snapdragon (*Antirrhinum majus* L.)

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Great attention to plant research is required to enhance growth performance and yield of small potted plants. Various growing media increased plant productivity while use of soil is going to be limited because of low fertility and numerous soil-borne diseases. Present pot experiment aimed to evaluate the performance of morpho-physiological and biochemical attributes in snapdragon cultivated under cocopeat (CP), pumice (P), leaf mold (LM) and their combination with silt (S), whereas silt alone was considered as control treatment. The results showed that LM and its combination with silt improved plant morphological attributes such as plant height (12%), leaf area (37.4%), spike length (54.9%), stem diameter (39.2%), number of florets spike^{-1} (38.6%), whereas, plant fresh weight, plant dry weight and soluble protein contents was improved by 24.1%, 17.7% and 59.2%, respectively, compared with control. Antioxidative enzyme activities such as POX and SOD, total phenolic capacity, antioxidant capacity, relative chlorophyll content and linear electron flow was enhanced by 27.2%, 296%, 47.1%, 64.9%, 27.4%, and 136.7%, respectively, in treatment containing combination of all growing media with equal ratio compared with control. Whereas quantum yield of photosystem-II, non-photochemical quenching and efficiency of photosystem-II was enhanced by 11.8%, 39.7%, and 7.9%, respectively, under combine CP+S growing media. This study opined that the application of LM and CP are great sources of macronutrients. Therefore, exploitation of these growing media and their combination with soil proves more operative cultivation media for producing high quality snapdragon while encouraging sustainable floricultural practices.

Keywords: Antioxidative enzyme; pumice; sustainable floriculture; metabolites; chlorophyll

INTRODUCTION

Snapdragon (*Antirrhinum majus* L.) belongs to family Plantaginaceae with 36 species and 20000 cultivars worldwide (Seo *et al.,* 2020). It is commonly known as snapdragon due to its hinged flowers that open and close like a dragon mouth when pinched at the sides with thumb. Cultivars of snapdragon are classified based on growth and flowering response to temperature and day length (Saqallah *et al.,* 2018). Because of its appealing color and mild smell, it is becoming increasingly popular as a cut flower as well as bedding plant around the world (Singh and Saxena, 2019).

The plants grown in the soilless culture are markedly better quality than that of plants cultivated in conventional soil (Karaguzel, 2020). Soilless growth surfaces are simpler to manage than soil that might create some more favorable conditions for growth (Ahmad *et al.,* 2020). These recyclable materials are frequently cheaper and make good substitutes because of their granularity, chemical stability, mechanical toughness, nutritional content, suitable aeration, water holding ability and water insolubility (Norhasnan *et al.*, 2021). However, it is important to determine the suitable growing media and use of organic and inorganic substrates. There are several local soilless culture substrates used in many countries and usage of cheap and local growing media with expedient chemical and physical properties is suggested worldwide (Gohil *et al.*, 2018). Soilless culture in plastic or wooden crates, pots and bags is the meekest and easiest way of growing plants. Other common benefits of soilless systems include plant nutrition control and no tillage requirements, thus improving the potential cultivation time as well as increase yield (Kamrani *et al.*, 2019). One most used media to produce floricultural crops is cocopeat (Putra *et al.,* 2019).

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Cocopeat is an organic growing media which is product of coconut husk (Marock, 2021). In potted plants, cocopeat can be utilized merely or combination with pumice, perlite, vermiculite amongst others (Kalaivani and Jawaharlal, 2019). In many cases, cocopeat is mixed at various concentrations of a soilless potting media to make a single constituent (Barrett *et al.,* 2016). Soils are commonly not suitable to produce plants in pot culture (Kimbonguila *et al.,* 2019). Production of plants in a soilless system is more lucrative than a soil medium (Kamrani *et al.,* 2019). Water holding capacity, aeration and drainage necessities are generally less in soils as compared to a media. Extensive adoption of soilless growing media for production of food globally has been observed as the solution for problems like less produce ability, soil fertility control, oxygen deficiency in root zone and soil borne diseases (Kala *et al.,* 2020).

Pumice is a sponge-like natural lightweight aggregate which is produced during the cooling and solidification of molten lava (Rashad, 2021). Pumice has been used as a plant-growing medium for a long time since it makes the soil lighter, facilitates ploughing, promotes soil aeration, and stores water (Kong *et al.,* 2021). For the purpose of water percolation, aeration and economical point of view, pumice has been extensively used for mixing with other substrates in soilless plant production (Perez-Urrestarazu *et al.,* 2019).

Compost of leaves is one of the most readily organic materials which is available abundantly from deciduous trees (Richardville *et al.,* 2022). Many farmers across the globe noted that soils amend with leaf mold leads to dramatic enhancements in yield and plant quality (Savini, 2018). Improving soils with leaf compost obtained from waste streams also had potential to provide other valuable ecosystem services like reducing erosion and improving water quality by retaining plant nutrients and elevating degradation of organic contaminants (Bernel *et al.,* 2017). This compost may also offer supplementary assistances like development of circular economies and making urban areas which are more sustainable in longer period (Egel *et al.,* 2019). Keeping in view the importance of different potting media, present study aimed to investigate the potting mixes for the morphological growth, physiological attributes, and biochemical characteristics of *Antirrhinum majus.* The specific objectives of this study were (i) to explore the ideal growing medium and its combinations with silt for the highest flower quality attributes of elegant snapdragon plants; (ii) to evaluate the physical and biochemical responses of *Antirrhinum majus* cultivated with leaf mold, cocopeat and pumice growing media.

MATERIAL AND METHODS

This comparative study was conducted at the experimental area of the Department of Horticultural Sciences, The Islamia University of Bahawalpur (29.3788° N, 71.7652° E) during 1st week of November 2021 to last week of April 2022. Seeds of *Antirrhinum majus* cv. Sonnet hybrid was purchased from Sunny View Seed Company Lahore, Pakistan. These seeds were sown in 9″ clay pots for nursery raising. Seedlings were transplanted after 30 d at 4 leaf stage in 9″ clay pots. Different potting media like pumice, cocopeat, leaf mold and silt were used alone and in different combinations as; T_1, silt (S); T_2, cocopeat (CP); T_3, pumice (P), T_4, leaf mold (LM); T_5, cocopeat + silt (1:1); T_6, pumice + silt (1:1); T_7, leaf mold + silt (1:1); T_8, cocopeat + pumice + leaf mold + silt (1:1:1:1). This experiment was set according to completely randomized design (CRD) with five plants in each treatment that were replicated thrice (fifteen plants per treatments). All cultural practices like weeding, irrigation and fertilization were the same for all treatments.

***Determination of the chemical composition of growing media*:** The pH and electrical conductivity of growing media was determined by using a pH meter and conductivity meter (DDS-11A) according to method described by Maltas *et al.* (2022). The total nitrogen in the growing media samples was estimated by distillation in Kjeldahl's apparatus and titration was carried out with H_2SO_4. Boric acid and methyl red was used as an indicator (Dong *et al.,* 2020). Phosphorus concentration in the soil was estimated according to methodology proposed by Dong *et al.* (2016). The measurement of potassium level was conducted on flame photometer according to methodology described by United States Salinity Laboratory Staff's (1954). The results of this analysis was presented in Table 1.

Table 1. Chemical composition of various growing media used in the experiment.

Growing media	pH	EC (dS m^{-1})	Total N (%)	Phosphorus (ppm)	Potassium (ppm)
T_1	6.86	1.45	0.71	85.4	991.7
T_2	7.21	2.19	0.88	70.3	686.1
T_3	8.25	0.19	0.11	45.6	359.4
T_4	6.95	1.12	1.36	199.3	928.8
T_5	6.84	1.11	1.62	123.5	1240.1
T_6	8.11	0.49	0.35	68.2	415.2
T_7	7.19	0.89	1.14	192.5	1430.6
T_8	7.12	1.13	2.49	106.2	1323.8

Measurement of morphological attributes and plant fresh and dry weights: Height of the plant and spike length of snapdragon were measured by using measuring scale whereas leaf area was estimated with the help of leaf area meter (LICOR-3000C, Lincon, NE, USA). Stem diameter was measured by using vernier caliper while number of florets was counted at last stage of the experiment. From the date to seed sowing to first bud appearance was counted. After harvesting, the fresh weight of the plant was measured on an electrical balance while dry weight was recorded after digestion at 70ºC for 48 h in an oven.

***Determination of soluble protein and antioxidant enzyme activity*:** Fresh leaf (0.5 g) was taken for the determination of soluble protein and extracted in an ice bath along with 10 mL potassium phosphate (50 mM). By following the procedure of Bradford (1976), the protein concentration in the extract was determined. The activities of antioxidant enzymes like catalase (CAT), peroxidase (POX) and superoxide dismutase (SOD) were estimated with the help of spectrophotometer. For this purpose, a 1.0 g fresh leaf sample was standardized with dithiothreitol (DDT) and 50 mM phosphate buffer (pH 7.0) as method suggested by Hassan *et al.* (2022). The activities of CAT and POX were determined according to procedure suggested by Liu *et al.* (2009) while SOD was estimated by following method described by Li *et al.* (2021).

***Estimation of total phenolics contents and total antioxidants capacity*:** By using folin-ciocalteu (F-C) reagent, total phenolics contents (TPC) were determined according to methodology suggested by Ainsworth and Gillespie (2007). The total antioxidants capacity (TAC) was determined by using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical assay by following protocol from Mimica-Duki´c *et al.* (2003).

***Measurement of chlorophyll inflorescence*:** Snapdragon leaves were clamped between the lens of PhotosynQ MultispeQ to measure relative chlorophyll content, quantum yield of photosystem II (Phi2), non-photochemical quenching (PhiNPQ), light lost to non-regulated processes (PhiNO), Efficiency of photosystem II (Fv/Fm), and linear electron flow (LEF) according to recommendations of Kuhlgert *et al.* (2016).

***Statistical analysis*:** All the data obtained were evaluated by analysis of variance (ANOVA) technique with the help of statistical software STATISTIX-8.1. All treatment means were statistically compared by LSD at a 5% level of probability.

RESULTS

Growing media like LM alone and its combination with silt noticeably increased plant height 11.2% and 12% respectively

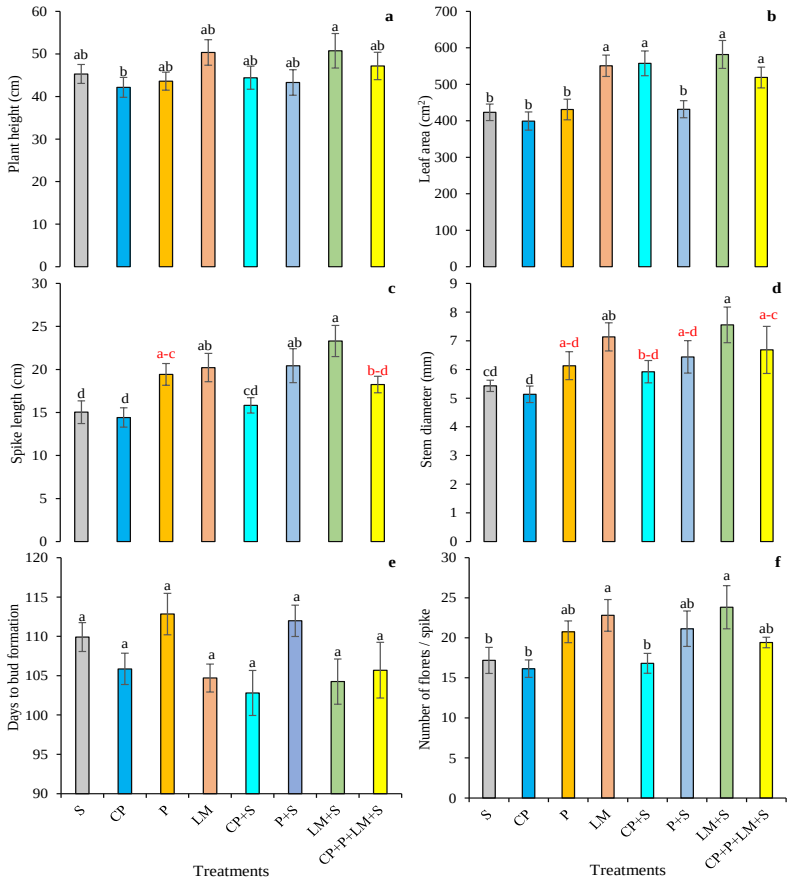


Figure 1. Impact of different growing media on plant height (a), leaf area (b), spike length (c), stem diameter (d), days to bud formation (e), and number of florets per spike (f) of *Antirrhinum majus.* Each bar shows a mean of three replicates ± SE. Dissimilar lettering illustrates significant statistical differences at $p \leq 0.05$ after applying LSD test.

than silt (control). Other potting media like CP and P along its combination with silt reduced plant length compared with silt (Fig. 1a). Snapdragon plants cultivated with LM and LM+S growing media significantly ($p \leq 0.05$) enhanced leaf area (30% and 37.4%) and spike length (34% and 55%) than control (silt). Both parameters showed increased value when plants grown under CP+S and P+S than CP and P alone. It is interesting to note that leaf area and spike length decreased 5.7% and 4.1% in plants grown with CP whereas plants cultivated under CP+S enhanced these attributes 31.6% and 5.3% respectively (Fig. 1b, c). Minimum days to bud formation was required in plants grown under CP+S medium (-6.5%) followed by LM (-4.8%). Highest number of days (112.9) were required to produced bud under found in plant grown with P (Fig. 1d). The maximum number of florets spike^{-1} and stem diameter was recorded in plants cultivated with LM (32.7% and 31.5%) and its combination with silt (38.6% and 39.2%). The combination of all growing media i.e. CP+P+LM+S produced 13% and 23.1% higher florets number and stem diameter than silt (Fig. 1e, f). Plant fresh and dry weights were significantly ($p \leq 0.05$) enhanced in *Antirrhinum majus* plants grown with LM and its combination with silt. There were 21.8% and 17.8% increments under LM while 24.1% and 4.3% increase with LM+S growing medium in fresh and dry plant biomass respectively than control (Fig. 2a, b).

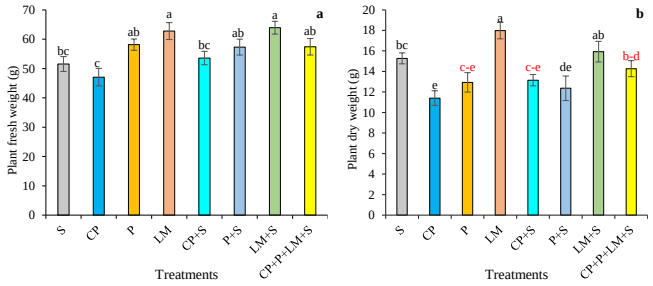


Figure 2. Influence of different growing media on plant fresh weight (a), and plant dry weight (b), of *Antirrhinum majus.* Each bar shows a mean of three replicates ± SE. Dissimilar lettering illustrates significant statistical differences at $p \leq 0.05$ after applying LSD test.

Statistically, there was significant ($p \leq 0.05$) impact of different growing media on soluble protein contents of *Antirrhinum majus.* Highest soluble protein contents were recorded in plants grown with LM alone (53.7%) and with silt combination (59.2%). The plant grown in CP potting media reduced protein contents up to -13.3% while its combination with S enhanced protein level 9.5% (Fig.3a). The antioxidant enzymatic activities were significantly increased under different growing media. The plants grown with CP+S produced the highest CAT activity (64.6%) whereas POD and SOD activities were recorded maximum in plants produced with treatment contained combination of all growing media (CP+P+LM+S) to 27.2% and 296% respectively (Fig. 3b, c, d).

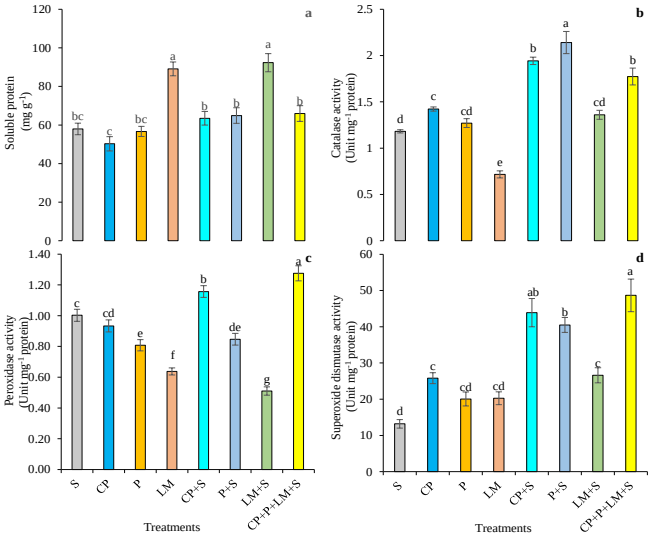


Figure 3. Influence of different growing media on soluble protein (a), catalase (b), peroxidase (c), and superoxide dismutase (d) of *Antirrhinum majus.* Each bar shows a mean of three replicates ± SE. Dissimilar lettering illustrates significant statistical differences at $p \leq 0.05$ after applying LSD test.

All growing media have significant ($p \leq 0.05$) impact on total phenolic contents (TPC) and total antioxidant capacity (TAC) of *Antirrhinum majus*. The plants cultivated under treatment containing combinations of all growing media contained highest TPC and TAC with concentration of 47.1% and 64.9% respectively than plants grown in silt (control) treatment (Fig. 4a, b).

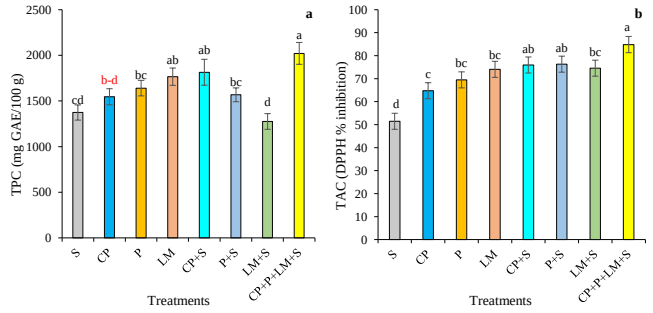


Figure 4. Influence of different growing media on total phenolic contents (a), and total antioxidant capacity (b), of Antirrhinum *majus.* Each bar shows a mean of three replicates ± SE. Dissimilar lettering illustrates significant statistical differences at $p \leq 0.05$ after applying LSD test.

Relative chlorophyll contents significantly ($p \leq 0.05$) reduced in plants produced in all growing media except treatment of LM alone and mixture of all growing media i.e. CP+P+LM+S. Highest chlorophyll was recorded in CP+P+LM+S treatment followed by LM alone with increase of 27.3% and 11.3% respectively than silt (control) treatment. The lowest chlorophyll (-36.3%) was found in plants grown with P+S growing media (Fig. 5a).

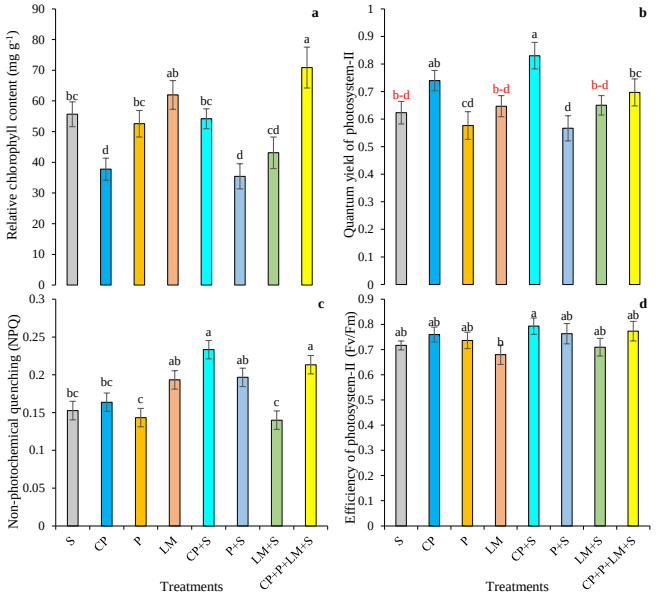


Figure 5: Influence of different growing media on relative chlorophyll content (a), quantum yield of photosystem II (b), non-photochemical quenching (c), and efficiency of photosystem II (d) of *Antirrhinum majus.* Each bar shows a mean of three replicates ± SE. Dissimilar lettering illustrates significant statistical differences at $p \leq 0.05$ after applying LSD test.

Quantum yield of photosystem-II and non-photochemical quenching values were recorded highest in plant grown with CP+S growing media. There was 33.2% and 52.9% increment in quantum yield of photosystem-II and non-photochemical quenching values than control treatment (Fig. 5b, c). The greatest efficiency of photosystem-II was found in plants cultivated with CP+S growing medium where 10.7% increment was recorded than plants produced under silt (control) treatment. The lowest photosystem-II efficiency (-5.1%) was found in LM grown plants (Fig. 5d). Linear electron flow was significantly enhanced in plants cultivated with CP+P+LM+S and CP+S with value of 136.7% and 91.4% respectively than silt (control) grown plants. The lowest electron flow was found in P+S growing media whose value (-22.5%) were lowest than controlled treated plant (Fig. 6).

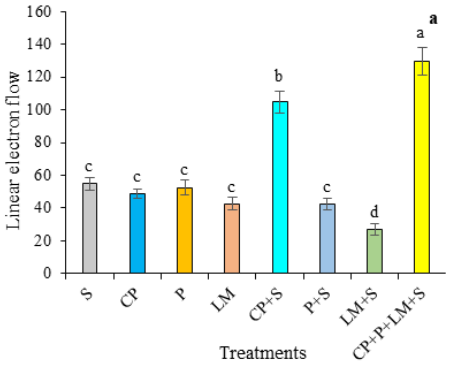


Figure 6. Influence of different growing media on linear electron flow (a) of *Antirrhinum majus.* Each bar shows a mean of three replicates ± SE. Dissimilar lettering illustrates significant and statistical differences at $p \leq 0.05$ after applying LSD test.

DISCUSSION

A balanced growing medium which possesses an adequate nutrient supply is vital for plants to attain the highest growth and development. Results showed that use of various growing media affects plants height and spike length. These morphological attributes were greatly affected by balanced rooting medium that contains optimum growing substrate with availability of essential nutrients for attaining vegetative growth of plants (Dabral *et al.*, 2019). The present study showed the greatest plant height and spike length with LM and its mixture with silt. Similar findings were recorded by Dubsky and Sramek (2008) who showed excellent morphological growth of perennials in LM along with rock wool mixture which resulted in highest plant height and stem length. Greatest plant length along with maximum leaves with LM growing media was also supported by Madurangani *et al.* (2020) and argued that organic materials from agriculture and forestry are richest source of various nutrients and strongly recommended for its utilization as renewable resources in potted plant production. The use of LM can efficiently improve the water holding capacity, drainage and aeration of a growing media (Kaushal and Kumari, 2020). Early floral bud formation, highest florets number, spike diameter and plant fresh as well as dry biomass were also encouraged with LM potting medium. These results were comparable with the finding s of Richardville *et al.* (2022) who showed greatest improvement in morphological attributes of horticultural plants with leaf mold compost. He further concluded that urban farmers could enhance the production of their farms by altering soils with leaf mold compost, which will assist to guarantee the long-term sustainability of urban farming creativities. The leaf mold provides nutrients early to the plant than other growing media and stimulated release of nutrients from previous crops too (O'Neill *et al.*, 2021). Composts like

LM with low C/N ratios also contain active organic matter pools which decompose comparatively speedily to release additional nutrients (Richardville *et al.,* 2022). In addition, these active pools of organic matter may arouse activity of soil microbes, encouraging decomposition of occupant soil organic matter, releasing extra plant available nutrients and P for uptake of plants (Lazcano *et al.*, 2013).

In plants, the total accrual of soluble protein concentrations differs from species to species (Ahsan *et al.,* 2022). In the present experiment, soluble protein contents were noticeably increased in plants produced under LM alone and combination with silt growing media than silt alone. The enhancement in soluble protein might be one of the major mechanisms for the improvement of chlorophyll and other physiological processes (Bernel *et al.,* 2017). Similar reports were provided by Qioa *et al.* (2021), who found an incremented protein concentration in plant leaves which were grown with leaf compost, which raises photosynthetic activities under mentioned growing medium. Enzymatic activities of snapdragon plants were significantly reduced with LM and silt alone indicating the decreased activity of the plants to withstand against oxidative injury and that is fewer valued and accepted by consumers and markets, who are looking for value added products of high antioxidant standings (Chrysargyris *et al.,* 2017). Antioxidants remained low, snapdragon plants were subjected to oxidative stress with the presence of silt and LM growing media alone resulting in peroxidation of lipids and cellular injury. Plants with silt and its combination with other growing media like CP and P activate the CAT, SOD and POD antioxidant enzymatic activities to detoxify the reactive oxygen species (ROS) accrual (Yu *et al.,* 2019). Plants retorted to oxidative stress by protection mechanism activation, producing injury response protein and antioxidant enzymes to resolve the accrual of ROS (Chrysargyris *et al.,* 2017). The chlorophyll content represents the plant health and a sign of appropriate functionality of photosynthetic apparatus. A well-proportionate media can affect the chlorophyll content of plants through efficient nutrient availability, hydration, and root oxygenation (Karaguzel, 2020; Jedmowski *et al.,* 2013). In the current study, plants grown on a mixture of cocopeat, pumice, leaf mold, and silt (1:1:1:1) synthesized the highest chlorophyll content, approximately two-folds that of the plants grown on a mixture comprising of only pumice and silt. Our findings agree with those of Popescu and Popescu (2015) who noted highest photosynthetic capacity in the plants of *Petunia grandiflora* and *Nicotiana alata* raised on mixture of various growing media including fallow soil, Biolan peat, acid peat, leaf compost, and perlite. Similarly, in another study by Sameei *et al.* (2004), the highest values of leaf area and chlorophyll content were observed in the plants of pothos (*Epipremnum aureum*) grown on cocopeat. Rahmah *et al.* (2023) also found significant improvement in chlorophyll levels of camphor (*Dryobalanops aromatica*) when raised on peat compared with mineral media. Thus, our study indicated that the substrates with good water holding capability and aeration lead to absorption of nutrients including nitrogen for the chlorophyll development in the Snapdragon's leaves. Moreover, the variations recorded for the relative chlorophyll content in the plants grown on different growing media can be attributed to differences in their bulk density, porosity, aeration, drainage, and water retention capacity which have a substantial impact on the root interception and diffusion of nutrients and hence ultimately influence the rate of photosynthates production (Hochmuth *et al.,* 2018; Hawkesford, 2014). The quantum yield of photosystem II (Phi2) depicts the ratio of light captured into photosystem II to make sugars, ATP, and NADPH, which is plant food. In the present study, Phi2 was 1.5 times higher in the plants grown on cocopeat and silt mixture than those grown on mixture of pumice and silt. The linear relationship between Phi2 and chlorophyll content has been well documented in many previous studies (Liu *et al.,* 2023; Dutbayev *et al.,* 2020; Cheng *et al.,* 2001). Non-photochemical quenching (PhiNPQ) is the ratio of incoming light that goes towards non-photochemical processes *i.e.,* the energy generated in this process is used to combat plant stress damage. The significant difference for Fv/Fm between the growing media, is in agreement with the previous studies (Papadimitriou *et al.,* 2024; Amoroso *et al.,* 2011), indicating that the physical properties of cocopeat and silt mixture had a stronger impact on efficiency of photosystem II. According to the findings of the current study, Fv/Fm was strongly affected by the type of growing media due to sharp reduction of the water content in the upper layer of the growing media. Linear electron flow (LEF) has become increasingly crucial to the plant growth, creating a pH gradient across the thylakoid membrane (ΔpH) that facilitates in the ATP synthesis and triggers the protective mechanism of PhiNPQ during stress. The regulation of electron transport also ensures a balance between the supply of light and the metabolic requirements. In our study, the plants grown on a mixture of all different experimental growing media (cocopeat + pumice + leaf mold + silt) were found to have a relatively highest LEF, approximately six times of that found in the plants grown on a mixture of only leaf mold and silt. The results of this study are in line with those of Popescu (2015), who recorded a relatively higher electron flow rate in plants of *Petunia grandiflora* and *Nicotiana alata* grown on a combination of fallow soil, acid peat, leaf compost, and perlite. Our findings are also in accordance with those of Papadimitriou *et al.* (2024), who noted a substantial impact of coir dust and perlite blends on photosynthetic capacity of *S. hispanicus* plants compared to those raised on individual ones. This might be due to the direct effect of growing media on LEF by regulating nutrient availability, soil structure, pH, and water retention.

***Conclusions*:** The present study confirms the fact that selection of appropriate growing media for potted flowering plants was very imperative for morphological and photosynthetic attributes. The medium must safeguard the production of plants of superior quality on cost effective basis. The current experiment illustrated that leaf mold and its combination with silt proved to be great source of NPK, which resulted in elevated physical quality parameters, plant fresh as well as dry biomass and soluble protein contents in *Antirrhinum majus*. Combination of silt with cocopeat and leaf mold stimulated the antioxidant enzymatic activities, secondary metabolites and photosynthetic attributes including chlorophyll contents, quantum yield and efficiency of photosystem-II, non-photochemical quenching, and linear electron flow. With the lowest macronutrients level in pumice and its mixture with silt medium, plants showed early floral bud formation and higher catalase activity. Thus, it is suggested that cocopeat and leaf mold may be most effective media, but its combination with silt proved to be an ideal substrate for quality production of *Antirrhinum majus*.

***Conflict of interest*:** The author declares that there is no conflict of interest.

***Authors' Contribution Statement*:** MAA, MA, and MN planned and executed the research, MRS and MWH provided reagents and analysis facilities, ER and HOE wrote and review the manuscript.

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REFERENCES

Ahmad, A., I. Ahmad and M.F.H. Ferdosi. 2020. Indigenous soilless substrate compositions affect growth, yield and quality of cut *Antirrhinum majus*. Sarhad Journal of Agriculture 36:586-592.

Ahsan, M., H. Zulfiqar, M.A. Farooq, S. Ali, A. Tufail, S. Kanwal, M.R. Shaheen, M. Sajid, H. Gul and A. Jamal. 2022. Strigolactone (GR24) application positively regulates photosynthetic attributes, stress-related metabolites and antioxidant enzymatic activities of ornamental sunflower (*Helianthus annuus* cv. Vincent's Choice) under salinity stress. Agriculture 13, 50.

Ainsworth, E.A. and K.M. Gillespie. 2007. Estimation of total phenolic content and other oxidation substrates in plant tissues using Folin-ciocalteu reagent. Nature Protocols 2:875-877.

Amoroso, G., P. Frangi, R. Piatti, A. Fini and F. Ferrini. 2011. Influence of different container typology on Ulmus minor plant growth and root morphology. Acta Horticulturae 923:247–254.

Barrett, G.E., P.D. Alexander, J.S. Robinson and N.C. Bragg. 2016. Achieving environmentally sustainable growing media for soilless plant cultivation systems – A review. Scientia Horticulturae 212:220-234.

Bernel, M.P., S.G. Sommer, D. Chadwick, C. Qing, L. Guoxue and F.C. Michel. 2017. Current approaches and future trends in compost quality criteria for agronomic, environmental and health benefits. Advances in Agronomy 144:143-233.

Bradford, M.M. 1976. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Annual Review of Biochemistry 72:248-254.

Cheng, L., L.H. Fuchigami and P.J. Breen. 2001.The relationship between photosystem II efficiency and quantum yield for CO_2 assimilation is not affected by nitrogen content in apple leaves. Journal of Experimental Botany 52:1865-1872.

Chrysargyris, A., E. Nikolaidou, A. Stamatakis and N. Tzortzakis. 2017. Vegetative, physiological, nutritional and antioxidant behavior of spearmint (*Mentha spicata* L.) in response to different nitrogen supply in hydroponics. Journal of Applied Research on Medicinal and Aromatic Plants 6:52-61.

Dabral, M., P. Punetha and M. Bohra. 2019. Assessment of different substrates for pot culture in calla lily (*Zantedeschia sprengeri*). International Journal of Chemical Studies 7:269-274.

Dong, J., X. Cui, S. Wang, F. Wang, Z. Pang and N. Xu. 2016. Changes in biomass and quality of alpine steppe in response to N & P fertilization in the Tibetan Plateau. PLoS One, 11: e0156146.

Dong, J., R. Che, S. Jia, F. Wang, B. Zhang and X. Cui. 2020. Responses of ammonia-oxidizing archaea and bacteria to nitrogen and phosphorus amendments in an alpine steppe. European Journal of Soil Science 71:940-954.

Dubsky, M. and F. Sramek. 2008. Crushed rock wool as a component of growing substrates. Acta Horitculturae 779:491-495.

Dutbayev, Y., N. Rametov, V. Tsygankov, R. Islam and N. Kuldubayev, 2020. Linear modeling approach of physiological features of soybeans. Eurasian Journal of Biosciences 14:5555–5560.

Egel, D.S., L. Hoagland, J. Davis, C. Marchino and M. Bloomquist. 2019. Efficacy of organic disease control products on common foliar diseases of tomato in field and greenhouse trials. Journal of Crop Protection 122:90-97.

Gohil, P., M. Gohil, J. Rajatiya, F. Halepotara, M. Solanki and V.R. Malam. 2018. Role of growing media for

ornamental pot plants. International Journal of Pure & Applied Bioscience 6:1219-1224.

Hassan, H., M. Amin, I.A. Rajwana, S. Ullah, K. Razzaq, H.N. Faried, G. Akhtar, U. Naeem-Ullah, M.A. Qayyum, M.M. Aslam, K. Ali, Z. Asghar, S. Nayab, A. Naz and H.W. Sahar. 2022. Nutritional functions and antioxidative enzymes in juice extract from two different maturity stages of low temperature stored phalsa (*Grewia subinaequalis* D.C.) fruit. LWT. 153.

Hawkesford, J. Malcolm, S. Kopriva and L. Kok, 2014. Nutrient use efficiently in plants. Springer Cham, New York.

Hochmuth, G., D. Maynard, C. Vavrina, E. Hanlon and E. Simonne. 2018. Plant tissue analysis and interpretation for vegetable crops in Florida. HortTechnology 28:1-48.

Jedmowski, C., A. Ashoub and W. Brüggemann. 2013. Reactions of Egyptian landraces of *Hordeum vulgare* and *Sorghum bicolor* to drought stress, evaluated by the OJIP fluorescence transient analysis. Acta Physiologiae Plantarum 35:345-354.

Kala, D., L.N. Mahawer and H.L. Bairwa. 2020. Response of potting media composition for pot mum chrysanthemum production (*Dendranthema grandiflora* L.). International Journal of Chemical Studies 8:1246-1251.

Kalaivani, K. and M. Jawaharlal. 2019. Study on physical characterization of coco peat with different proportions of organic amendments for soilless cultivation. Journal of Pharmacognosy and Phytochemistry 8:2747-749.

Kamrani, H.M., R.A. Chegeni and H. Hosseinniya. 2019. Effects of different growing media on yield and growth parameters of potato minitubers (*Solanum tuberosum* L.). Communications in Soil Science and Plant Analysis 50:1838-1853.

Karaguzel Ö. 2020. Effects of different growing media on the cut flower performances of oriental two *Lilium* varieties. International Journal of Agricultural and Biological Engineering 13:85–92.

Kaushal, S. and P. Kumari. 2020. Growing media in floricultural crops. Journal of Pharmacognosy and Phytochemistry 9:1056-1061.

Kimbonguila, A., L. Matos, J. Petit, J. Scher and J.M. Nzikou. 2019. Effect of physical treatment on the physicochemical, rheological and functional properties of yam meal of the cultivar "ngumvu" from *Dioscorea alata* L. of Congo. International Journal of Recent Scientific Research 8:19328-19334.

Kong, C., M. Camps-Arbestain, B. Clothier, P. Bishop, F.M. Vázquez. 2021. Use of either pumice or willow-based biochar amendments to decrease soil salinity under arid conditions. Environmental Technology and Innovation 24:101849.

Kuhlgert, S., G. Austic, R. Zegarac, I. Osei-Bonsu, D. Hoh, M.I. Chilvers, M.G. Roth, K. Bi, D. TerAvest, P. Weebadde and D.M. Kramer. 2016. MultispeQ Beta: a tool for large-scale plant phenotyping connected to the open PhotosynQ network. Royal Society Open Science 3:160592.

Lazcano, C., M. Gómez-Brandón, P. Revilla and J. Domínguez. 2013. Short-term effects of organic and inorganic fertilizers on soil microbial community structure and function. Biology and Fertility of Soils 49:723-733.

Li, Z., H. Cao, Y. Yuan, H. Jiang, Y. Hu, J. He, Y. Zhang and S. Tu. 2021. Combined passivators regulate the heavy metal accumulation and antioxidant response of *Brassica chinensis* grown in multi-metal contaminated soils. Environmental Science and Pollution Research 28:49166-49178.

Liu, D., J. Zou, Q. Meng and W. Jiang. 2009. Uptake and accumulation and oxidative stress in garlic (*Allium sativum* L.) under lead phytotoxicity. Ecotoxicology 18:134-143.

Liu, S., Z. Xiong, Z. Zhang, Y. Wei, D. Xiong, F. Wang and J. Huang. 2023. Exploration of chlorophyll fluorescence characteristics gene regulatory in rice (*Oryza sativa* L.): a genome-wide association study. Frontiers in Plant Science 14:1234866.

Madurangani, H.G.A.M.P., H.K.L.K. Gunasekera, M.C. Wickramasinghe. 2020. Investigation of best potting media to enhance flowering performance of *Petunia hybrida*. Journal of Agronomy and Agricultural Science 3:26.

Maltas, A.S., I.E. Tavali, I. Uz, M. Kaplan. 2022. Monitoring the effects of pH and EC regulated drip fertigation on microbial dynamics of calcareous soil in tomato (*Solanum lycopersicum* L.) cultivation under greenhouse conditions in a Mediterranean climate. Scientia Horticulturae 306:111448.

Marock, D. (2021). How do I buffer Coco Peat? Buffering Coco Coir. 1–10. https://www.lichengroup.co.za/buffering-coco-peat

Mimica-Duki´c, N., B. Bozin, M. Sokovi´c, B. Mihajlovi´c and M. Matavulj. 2003. Antimicrobial and antioxidant activities of three mentha species essential oils. Planta Medica 69:413-419.

Norhasnan, N.H.A., M.Z. Hassan, A.F.M. Nor, S.A. Zaki, R. Dolah, K.R. Jamaludin and S.A. Aziz. 2021. Physical mechanical properties of rice husk/coco peat reinforced acrylonitrile butadiene styrene blend composites. Polymers 13:1171.

O'Neill, B., C.D. Sprunger and G.P. Robertson. 2021. Do soil health tests match farmer experience? Assessing biological, physical, and chemical indicators in the Upper Midwest United States. Soil Science Society of America Journal 85:903-918.

Papadimitriou, D.M., I.N. Daliakopoulos, I. Louloudakis, T.I. Savvidis, I. Sabathianakis, D. Savvas and T. Manios. 2024. Impact of container geometry and hydraulic properties of coir dust, perlite, and their blends used as growing media, on growth, photosynthesis, and yield of Golden Thistle (*S. hispanicus* L.). Scientia Horticulturae 323:112425.

Pérez-Urrestarazu, L., R. Fernández-Cañero, P. Campos-Navarro, C. Sousa-Ortega and G. Egea. 2019. Assessment of perlite, expanded clay and pumice as substrates for living walls. Scientia Horticulturae. 54:48-54.

Popescu, G.C. and M. Popescu. 2015. Effects of different potting growing media for *Petunia grandiflora* and *Nicotiana alata* Link & Otto on photosynthetic capacity, leaf area, and flowering potential. Chilean Journal of Agricultural Research 75:21-26.

Putra, F.P., S. Saparso, S.R. Suparto and K. Faozi. 2019. Relationship of growth and yield mini tubers of potato under cocopeat media and frequency of fertilizer. Bernas 15:11-19.

Qiao, C., C.R. Penton, C. Liu, C. Tao, X. Deng, Y. Ou, H. Liu and R. Li. 2021. Patterns of fungal community succession triggered by C/N ratios during composting. Journal of Hazardous Materials 401:123344.

Rahmah, T.N., F.G. Dwiyanti, M. Rafi, U.J. Siregar and I.Z. Siregar. 2023. Effects of two contrasting potting media on the leaf development index, photosynthetic rate, and metabolite profile of camphor (*Dryobalanops aromatica*) seedlings. Heliyon 9: e12488.

Rashad, A.M. 2021. An overview of pumice stone as a cementitious material – the best manual for civil engineer. Silicon 13:551-572.

Richardville, K., D. Egel, A. Flachs, A. Jaiswal, D. Perkins, A. Thompson and L. Hoagland. 2022. Leaf mold compost reduces waste, improves soil and microbial properties, and increases tomato productivity. Urban Agriculture and Regional Food Systems 7:20022.

Sameei, L., A. Khalighi, M. Kafi and S. Samavat. 2004. Peat moss substituting with some organic wastes in pothos (*Epipremnum aureum* 'Golden Pothos') growing media. Iranian Journal of Horticultural Science and Technology 6:79-88.

Saqallah, F.G., W.M. Hamed, and W.H. Talib. 2018. In vivo evaluation of *Antirrhinum majus'* wound-healing activity. Scientia Pharmaceutica. 86:45.

Savini, F. 2018. The economy that runs on waste: Accumulation in the circular city. Journal of Environmental Policy and Planning 21:675-691.

Seo, J., J. Lee, H.Y. Yang and J. Ju. 2020. *Antirrhinum majus* L. flower extract inhibits cell growth and metastatic properties in human colon and lung cancer cell lines. Food Science and Nutrition. 8:6259-6268.

Singh, S. and A.K. Saxena. 2019. Evaluation of inbreds and their f_1s for flowering and post-harvest attributes in snapdragon (*Antirrhinum majus* L.). International Journal of Research and Review 6:441-447.

United States Salinity Lab. Staff (1954). Diagnosis and improvement of saline and alkali soil. Richards (ed.) Washington D.C. United States Department of Agriculture.

Yu, P., Q. Li, L. Huang, G. Niu and M. Gu. 2019. Mixed hardwood and sugarcane bagasse biochar as potting mix components for container tomato and basil seedling production. Applied Sciences 9:4713.