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Study of the Phenology of Saffron (*Crocus sativus* L.) Grown in Soilless Media under Protected Environment

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Traditionally grown in soil, saffron cultivation has been plagued by limited arable land, variable climate conditions, and soil-borne diseases. Phenological studies of the crop during each of its growth stages are crucial for mitigating the detrimental consequences of climate change, to which saffron crop is extremely susceptible. These also help in anticipating the future farming systems that involve crop cultivation methods, irrigation, field, and crop management. In this study, we assess the adaptability of saffron to soilless cultivation. In order to evaluate the performance of saffron grown in soilless media, a crop experiment was carried out over the course of two years, beginning in 2020 and continuing into 2021. Bulbs were planted in plastic polytunnels under two experimental treatments viz. soil-based (PS1) and soilless (PS2), supplemented with adequate nutrients. To evaluate the performance of saffron in soilless culture and to compare it with protected soil-based cultivation, saffron growth indicators were measured a total of twenty-five times at intervals of around twenty days during the entire growing period. The study of growth indices demonstrated that the PS2 (protected soilless cultivation) outperformed PS1 (protected soil-based cultivation) in terms of growth of organs (foliage, roots, mother bulbs, daughter bulbs) and biomass accumulation. In light of these findings, it has been demonstrated that soilless cultivation can be an effective method for the production of saffron.

Keywords: Protected cultivation; soilless cultivation, soil-based cultivation, saffron, growth indicators, phenology.

1. INTRODUCTION

The term "saffron" refers to a spice that is typically derived from the desiccated stigmas of the Crocus sativus plant, which has been predominantly cultivated for economic purposes since ancient times. Saffron holds the distinction of being the most expensive spice in the world and is often referred to as “red gold” [1,2]. The dried crimson stigmas of the Crocus flower are considered to be its most valuable component. Due to the constituents responsible for the aroma (safranal), flavour (picrocrocin), and pigment (crocin) of the spice being concentrated in the red stigmatic lobes of the flower of the Crocus sativus plant, these red scarlet stigmas are of great commercial value [3]. The highest grade saffron is believed to come from India, specifically Union Territory of Jammu and Kashmir, as this region has a long history of cultivating the precious spice [4,5]. Even though there have been reports of successful attempts to cultivate saffron in other parts of India such as Uttar Pradesh and Himachal Pradesh as well as in other regions of J&K state such as Kargil, the vast majority of the nation's saffron production is confined to the region of Kashmir. Saffron is grown in Kashmir in the uplands, which are called 'Karewas' in the local dialect [6]. These uplands are lacustrine deposits located at an altitude of 1585 to 1677 metres above mean sea level (amsl) where the climate is temperate [7]. The soils have a heavy texture, with silty clay loam as the main texture in upper strata and silty clay as the major texture in lower horizons [8,9]. Silty clay is the predominant texture throughout the soil. These soils have been classified as alfisols and have excellent drainage [10].

Nevertheless, it has been reported that saffron production in Kashmir has decreased significantly, possibly due to effect of weather [11]. Saffron production is particularly sensitive to variations in the weather since the saffron crop has very specific requirements for its proper growth. The saffron growing areas, which are most commonly referred to as the "Karewas," are known for experiencing erratic weather behavior. These include seasonal weather changes, in addition to the unpredictable and fluctuating weather patterns. It is anticipated that the frequency and severity of these extreme weather events would increase as a direct consequence of climate change. The cultivation of saffron may be affected by factors such as rising temperatures, changed patterns of precipitation, and an increase in the frequency of extreme weather events [12]. Lack of precipitation at the critical stages of growth and higher rates of evapotranspiration as a result of the climatic variability can cause crop failure in saffron [13]. Despite the fact that this crop has been grown in the Kashmir region for an extensive span of time, there has not been much development in the technology used for its production or processing. At present, there exist no strategies to mitigate the adverse impacts of climate variability.

The production of saffron may be negatively impacted by the long-term implications of climate change [14]. The flowering process in saffron can be disrupted by erratic weather conditions such as sudden fluctuations in temperature, excessive rainfall, or drought [15]. Extreme temperatures, especially during the flowering period can result in poor flower development, and reduced stigma yields. Excessive rainfall during the flowering period might result in flower damage and a significant reduction in yield. On the other hand, drought conditions can cause plant stress, which in turn can result in decreased flower production and bulbs of a smaller size, ultimately affecting yield. Climate variability can also have an impact on the growth and quality of saffron bulbs. The growth and development of saffron bulbs can be hindered by unfavorable weather, such as prolonged heatwaves or extreme cold spells. Insufficient chilling periods during the corm dormancy phase can lead to inadequate corm sprouting and subsequent poor vegetative growth. The unpredictable patterns of weather can generate conditions that are favorable for the spread of pests and diseases, posing additional challenges for saffron cultivation. Fungal diseases, such as corm rot, leaf blight, and root rot can become more prevalent due to sudden temperature shifts, prolonged periods of wetness, and excessive humidity [16,17]. Managing the moisture content of the soil to grow saffron can be difficult if the weather is unpredictable, particularly if there are erratic patterns of precipitation. Saffron plant's health, flower, and bulb production, can all be negatively impacted by water stress, which can be caused by insufficient rainfall or drought conditions. Conversely, heavy and excessive rainfall can result in waterlogging, which in turn can cause corm rot, damage the roots, and a reduction in yields [18,19]. In light of the information presented above, the development and investigation of novel techniques of saffron production becomes vital in mitigating the effects of variable weather on saffron production and further improving the technology of saffron production [20].

Soilless cultivation is an unconventional approach to crop production that eliminates the reliance on conventional soil-based cultivation [21,22]. This method precludes the traditional use of soil as a growing medium for plant growth. In the absence of soil, plants are grown under controlled conditions using a nutrient-rich solution (hydroponics) or other inert substrates (soilless culture) that provide support and directly deliver essential nutrients to the plant roots. The roots of the plant are suspended in an inert medium, such as perlite, coconut coir, vermiculite, peat moss, or rockwool [23]. These media provide the plants with physical support and facilitate nutrient absorption. A meticulously balanced nutrient solution is delivered directly to the roots of the plants, providing them with the necessary nutrients. Due to limited arable land availability, resource efficiency, improved yields and crop quality, climate adaptation capabilities, technological advancements, sustainability benefits, and increased knowledge sharing, soilless cultivation has emerged as a promising crop production method in recent years. Soilless cultivation is an optimistic strategy for future food security due to its potential to overcome land constraints, optimize resource utilization, and mitigate climate change effects [24]. Overall, soilless cultivation is a prospective method of crop production, as it offers adaptability, precision, and sustainability in the face of various agricultural challenges. It continues to evolve with advancements in technology, research, and innovation, contributing to the future of agriculture [25].

In recent years, soilless cultivation techniques have garnered attention as a promising alternative for sustainable and controlled crop production. The soilless technique of crop cultivation holds enormous potential as a crop production method for saffron, as it provides a multitude of advantages that can improve the production and yield [26]. Its ability to provide optimal nutrient management, precise water control, disease and pest control, climate adaptation, year-round production, higher yields, improved quality, and sustainable practices makes it an appealing alternative to traditional soil-based saffron production. The production of saffron can be improved by harnessing the benefits offered by soilless cultivation, which would help in promoting healthy bulb development, robust daughter bulb formation, flower production, and ultimately, higher saffron yields. Despite this, it is important to point out that the investigation of soilless growing techniques for saffron is still in its infancy, and there is still a great deal of research that needs to be done.

While soilless cultivation techniques have been widely studied for various crops, saffron-specific research remains limited. Saffron is a plant that differs significantly from other conventional cultivated plants in terms of its ecological, physiological, and phenological characteristics. Regarding saffron cultivation in Kashmir, the growing medium, availability of nutrients and water, and the surrounding environment all play a significant role. These resources can be manipulated for increased efficiency and production. There is a significant knowledge gap regarding the feasibility and potential of soilless techniques for saffron production, as a great deal of existing literature on saffron cultivation focuses primarily on traditional field-based methods. The limited research conducted so far has focused mostly on investigating the fundamental requirements and practicability of soilless cultivation for saffron. Nevertheless, there are no similar research studies available for the Kashmir region. In addition, there are insufficient studies on the behavior and performance of saffron in soilless culture in relation to its phenology. Understanding the effects of this crop cultivation technique on growth indicators of saffron is essential for the design and implementation of effective soilless cultivation systems. These complexities necessitate focused research efforts on the phenological studies of saffron grown without soil.

2. MATERIALS AND METHODS

In order to evaluate the performance of soilless culture for the cultivation of saffron (*Crocus sativus* L.) and comparison with protected soil-based cultivation, a crop experiment was carried out under the protected conditions of plastic polytunnels of semi-circular design and North-South orientation. Solar radiation was the only source of light within the polytunnels, and ventilation was used to regulate both humidity and temperature. The polytunnels were able to successfully produce temperature increases that were around 4 ºC higher than the surrounding air temperature. The investigation was carried out over the course of two years, from 2020 to 2021, at a research farm, Pampore, Jammu and Kashmir (latitude: 34.0060° N; longitude: 74.9238° E; elevation: 1585 meters above sea level). Research was performed on the temporal sub population of saffron that was acquired from the Saffron Research Station of the Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir. In each polytunnel, healthy, disease-free, and uniform bulbs weighing between 10 and 12 g were planted at a depth of 15 cm in the growing medium (soil or soilless) on 14th August, 2020. On 26th October, 2020 the last flush of flowers was harvested and this date was taken as the date of planting (DAP) for saffron bulbs during the experiment. The bulbs were treated as a preventative measure against corm rot before being planted in polytunnels. In order to accomplish this, the bulbs were first dipped in 0.2% carbendazim solution [27] and then drying using forced ventilation.

2.1 Protected Soil-based Cultivation (PS1)

In the soil-based cultivation, a small plastic polytunnel was erected to a height of approximately 60 cm on the soil. As recommended in the practical manual titled “Good Practices for Saffron Production in Kashmir,” the soil was deeply ploughed to a depth of approximately 25 cm. Saffron bulbs treated with the fungicidal suspension were planted in rows at a depth of 15 cm and spacing of 10 × 10 cm. After they were planted, the bulbs were watered to meet the water requirement of 700 m^3 per hectare that is recommended in the manual (Good Practices for Saffron Production in Kashmir). This was distributed over a total of ten fertigation sessions, delivering a volume of 0.05 m^3 of the nutrient solution in total over the entire crop growing season. The freshly prepared nutrient solution with an electrical conductivity of approximately 2.5 dS m^{-1} was introduced during each fertigation event. This was done in accordance with the instructions provided by [28]. In accordance with the directions provided in the manual, fertilization was also performed. No chemical measures were practiced for rodent control, however, bottom of the polytunnels were sealed with wooden planks to prevent the entry of rodents. This proved to be effective measure in the absence of chemical control. Due to the residual effect of chemical weedicides on saffron, their use is not recommended under Kashmir conditions. Weeding was carried out in November and then again in February. In addition to this, any weeds that emerged on the surface were pulled out by hand as soon as they were spotted.

2.2 Protected Soilless Cultivation (PS2)

Plastic polytunnel of the same dimensions as those used in soil-based cultivation were established in the soilless cultivation trial. Inside the polytunnel, saffron bulbs were planted in plastic containers of appropriate size. The plastic containers were filled to a depth of 20 cm with a soilless substrate (1:1 mixture of peat and crushed silica). In the same manner as with soil-based cultivation, the fungicidal suspension was applied to the bulbs before they were planted. The bulbs were then planted in rows at a spacing of 10 × 10 cm and a depth of 15 cm in the soilless substrate. For fertigation, a standard hydroponic fertilizer solution for fruiting crops marketed under the brand name "Radongrow" was used. During the entire growing period, the electrical conductivity and pH of the soilless medium were manually measured using an electrical conductivity meter (HM Digital COM-80: EC/TDS Hydrotester) and pH meter (Ohaus ST20 pH Pen Meter, Waterproof, 0.01 pH) respectively. The electrical conductivity and pH value obtained in the soilless growing substrate were taken into consideration while planning the timing of the fertilization. This resulted in approximately twenty-two fertigation events over the entire growth cycle of the crop. Rodent and weed management inside the polytunnel was carried out in a manner that was analogous to the soil-based cultivation.

2.3 Plant Sampling, Data Collection, and Analysis

To evaluate the performance of saffron in soilless culture and to compare it with protected soil-based cultivation, saffron growth indicators were measured using a destructive technique. The effect of growing media on the phenological parameters of saffron was studied so that a comparison may be made between the two techniques of cultivation. During the course of the growth cycle of saffron, plant sampling was carried out twenty-five times at intervals of around twenty days. At each of the sampling dates, three representative bulb samples were taken resulting in three replications per treatment. The phenological growth stages of the sample bulbs from the two different treatments were compared and contrasted. The initial sampling took place twenty days after planting (at 20 DAP), while the final sampling took place two hundred days following planting (200 DAP). At each sampling date, the growth indicators of saffron were quantified. The studied growth traits included the foliage dry weight, root dry weight, mother bulb weight, and daughter bulb weight.

In order to accomplish this, for each treatment all the leaves were detached off carefully from the bulbs being sampled. The saffron leaf samples that were collected from the sampled bulbs were weighed, and the readings were recorded as the fresh weight of the foliage. Each foliage sample was then put in a separate brown paper bag, after which it was placed in an oven set to approximately 70 °C for forty-eight hours. This process was carried out until the constant weight of the samples was achieved. After the leaf samples were oven dried, their weight was measured on a weighing scale, and the reading was recorded as the foliage dry weight. For root dry weight calculation, representative bulbs were extracted from the growing medium and their roots were cut away. The same procedure that was followed for determining the dry weight of foliage, was used for the dry weight estimation of roots. In order to determine the mother bulb weight, sampled mother bulbs were lifted from the growing medium, cleaned, and simply weighed on a weighing scale. For the purpose of computing the weight of the daughter bulbs, the sampled mother bulbs were removed from the growing media and the daughter bulbs were carefully detached from their respective mother bulb. The daughter bulbs were wiped off the growing media and weighed individually on a weighing scale.

For the experiment, a simple, completely randomized arrangement was followed with the cultivation method as the only factor. For the purpose of evaluating the performance of saffron bulbs in response to the two treatments (soil-based and soilless), data were gathered and recorded. Sample saffron bulbs from each cultivation method were systematically chosen and then analyzed for various phenological growth parameters. A one-way analysis of variance was carried out in OP STAT in order to analyze the impact that different growth systems have on the overall performance of the saffron crop.

3. RESULTS AND DISCUSSION

3.1 Foliage Dry Weight

The foliage weight variations during the entire duration of the experiment have been presented in Fig. 1. The protected soilless cultivation (PS2) treatment had foliage dry weight values that were, on average, somewhat greater than the protected soil-based treatment (PS1) for all the sampling dates. The higher foliage dry weight values that usually correspond to the superior vegetative performance of bulbs under the soilless cultivation (PS2) can be explained by the improved nutrient availability and management in the soilless substrate. This was demonstrated by the fact that PS2 yielded a larger percentage of bulbs with higher foliage dry weight values. Both of the cultivation methods resulted in an increase in the foliage dry weight up to the 120th day after planting (DAP). The foliage growth rate was highest at this point, indicating an optimal growth period for the saffron plants in both cultivation methods. After the point of peak growth, however, the values began to drop off significantly and did not reach zero until May (at the 200 DAP). This indicates a cessation of vegetative growth or the onset of dormant phase for the saffron. This finding is consistent with the findings that were presented by researchers [29] and [30], who claimed that the saffron foliage attained its maximum size between the months of January and February. Midway through the month of February (at 120 DAP), the experimental treatments (PS1 and PS2) each saw their respective foliage weights achieve their maximum value. According to the findings of [31], the foliage length of saffron increased up to 125 days after emergence and then decreased significantly. Our findings are consistent with this observation. In another study, [32] concluded that the maximum values of foliage dry weight, foliage length, root length, and root dry weight were found in soilless media supplemented and amended with specific elements. Overall, both soil-based cultivation (PS1) and soilless cultivation (PS2) exhibit relatively similar growth patterns, with PS2 exhibiting slightly higher growth rates throughout most of the growing period. This indicates that in comparison to soil-based cultivation (PS1), the vegetation under protected soilless cultivation (PS2) grew more vigorously. This is consistent with what [33] discovered in their investigation.

3.2 Root Dry Weight

Based on the sampling results depicted in Fig. 2, the root dry weight increased at the beginning of the growing season and continued to rise until the middle of February. After that, it began to exhibit a decreasing trend up to the end of vegetative phase in May. In a study on saffron conducted by [29], it was demonstrated that the root weight increased up to 90 days after the initial irrigation and then continued with a decreasing trend. The measure of this root growth index in the final two months of the growing season was very little, finally reaching zero in May (at 200 days after planting), when the corms could be readily detached from the soil. It was observed that after the first irrigation in the autumn, fibrous roots began to develop in saffron plants in order for them to absorb in water and nutrients. This increased growth of roots continues for around another four months. But towards the end of winter and in early spring, the root expansion slowed down, and with it, the absorption capacity of the root system reduced. In correspondence with this observation, a number of studies suggest that soil nutrition needs to be addressed prior to the deterioration of the root system. One such study by [25] suggested that the foliar application of nutrients during the final phase of the vegetative cycle of saffron may serve as an effective method for enhancing the growth of replacement corms. In a study that was quite similar to the previous one [30], it was discovered that the pattern of root growth that occurred throughout the life cycle of plants was dependent on the weight of the mother bulb. Nevertheless, it was reported that the root weight of saffron increased at the start of the growing season (120 days after growth), but that this was followed by a tendency of decreasing root weight all the way up until the end of the vegetative growth phase in the middle of spring. Both the experimental treatments (PS1 and PS2) reached their maximum root dry weight values on 140 days after planting (DAP). It was observed that the root spread on most sampling occasions was greater in soilless cultivation (PS2) as compared to the soil-based cultivation (PS1). The soil-based cultivation (PS1) plants demonstrated outstanding root growth up to 80 days after planting (DAP) after which the rate of root expansion slowed down significantly. However, the soilless cultivation (PS2) plants showed a consistent increase in root dry weight in the beginning of the crop growth cycle, reaching a plateau between 100 and 140 days after planting (DAP). The minor fluctuation in the root growth rate values during this period, suggested a relatively consistent growth pattern. These findings were congruent with those of [33], who found that foliage growth, root spread, and leaf gas exchange greatly enhanced under soilless culture in an indoor saffron farming system. In general, the trend of the data indicates an initial gradual increase in the root growth, followed by a period of peak growth, and then a decline in growth rate. The growth patterns are generally similar for both soil-based (PS1) and soilless (PS2) cultivation, but soilless cultivation (PS2) consistently exhibits higher root growth rates compared to soil-based cultivation (PS1) throughout most of the crop growing period.

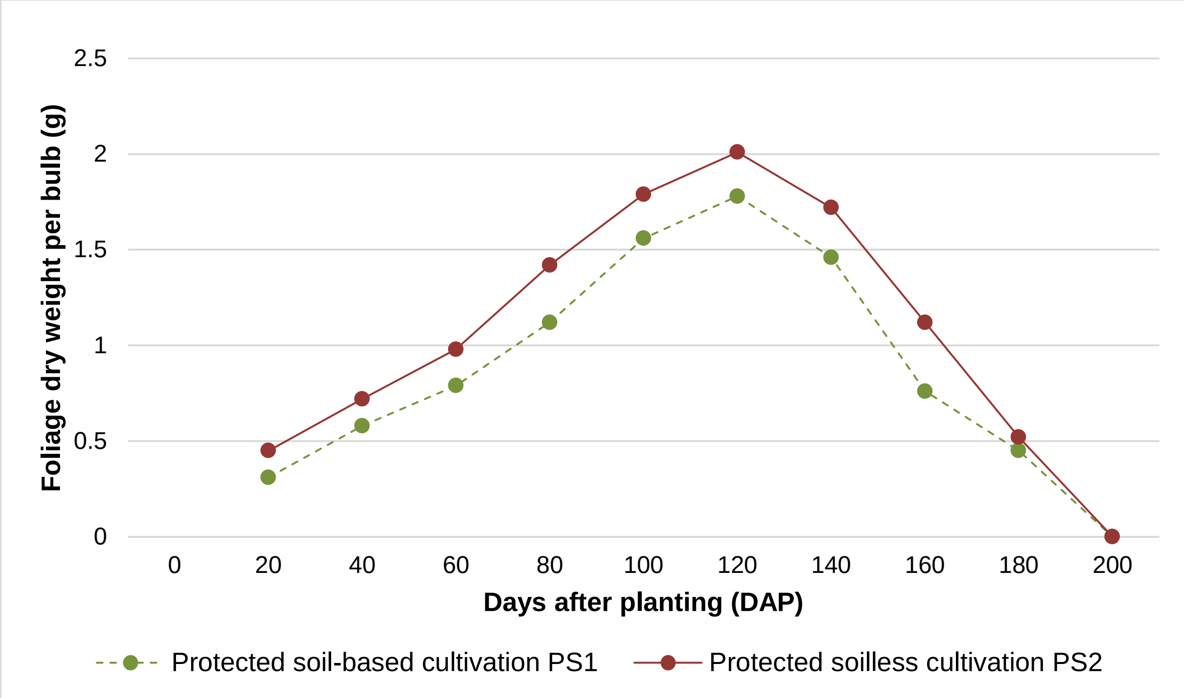

Fig. 1. Foliage dry weight changes during saffron growth cycle (26th October – 13th May)

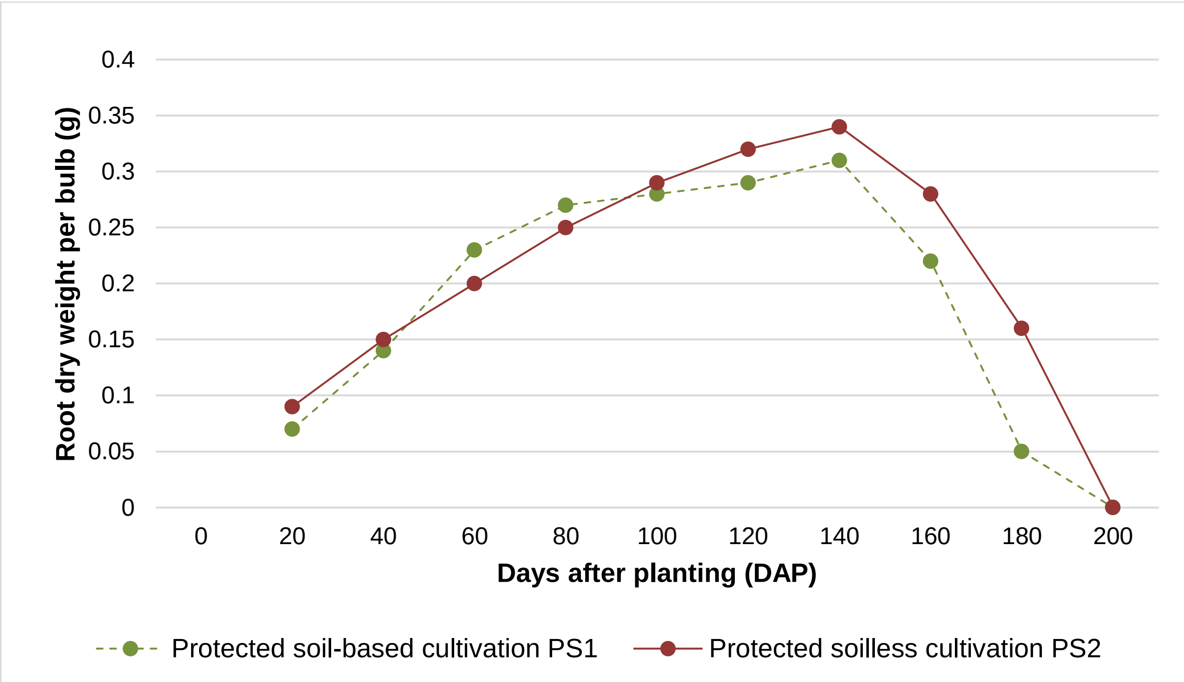

Fig. 2. Root dry weight changes during saffron growth cycle (26th October – 13th May)

3.3 Mother Bulb Weight

On the basis of the analysis of the mother corm weight changes over the entire saffron growth cycle, presented in Fig. 3, it can be inferred that mother corm weight decreased gradually from first up to the end sampling event. Before the first sampling event, the bulk of the mother bulb's nutrient reserves (more than 50%) had been utilized for flowering. As a result of this, the weight of mother bulbs after flowering decreased from approximately 10 g prior to flowering to less than 5 g, only twenty days after flowering. According to [29], who conducted a study that was quite similar to the present one, roughly 20–30% of the mother corm reserves are mobilized in order to facilitate the development of the roots, flowering, and foliage. Further, [31] stated that it takes up to 40 days following leaf emergence, the allocation of mother corm nutrient reserves for the foliage growth, after which the remaining reserves are used for the production of new bulbs. After this date (40 days following leaf emergence), the leaves progressively become independent, but their share in the filling of replacement bulbs is still low up until 80 days after emergence, when leaf photosynthetic capability is maximized. These conclusions are supported by the results provided in our data. Up to 140 days after planting (DAP), the weight of the mother bulbs for both cultivation methods decreased gradually, suggesting the allocation of mother bulb reserves for the foliage expansion and an increase the growth of the saffron plants. This is supported by the fact that the foliage attained its maximum dry weight value around this time, as indicated by the results of foliage dry weight. After this period, there are some minor fluctuations in the growth rate of bulbs for both soil-based (PS1) and soilless (PS2) cultivation as influenced by the cultivation method (type of growing media). The weight of the mother bulb continues to decrease due to the phenomenon of remobilization of photo-assimilates, in which biomass is translocated from leaves to replacement bulbs towards the end of growth cycle. The reducing trend of the mother corm weight persists following flowering and leaf emergence until 200 days after planting (DAP). Subsequently, only scales and bulb remnants remain, which lack essential nutrients. Throughout the course of the investigation, soilless (PS2) cultivation maintained a relatively stable growth rate, with minimal fluctuations. Soil-based (PS1) cultivation, on the other hand, experienced more fluctuations in growth rate, reflecting a less consistent growth pattern.

3.4 Daughter Bulb Weight

Fig. 4 represents the growth performance of saffron (daughter) bulbs for two different cultivation methods viz. protected soil-based cultivation (PS1) and protected soilless cultivation (PS2). By comparing the results, we can observe that the daughter bulb weights in both the cultivation methods showed continuous increasing trend during the entire growth cycle. In both the experimental treatments (PS1 and PS2), the replacement bulb formation was initiated about 20 days after planting (DAP). However, on almost all sampling occasions, the daughter bulb weight for soilless cultivation (PS2) was substantially greater than that for soil-based cultivation (PS1). Mean weight of the replacement bulbs was significantly influenced by the treatments (growing medium). The soilless growing media found to have a positive effect on the bulb production under the protected conditions. Soilless cultivation (PS2) consistently exhibits higher growth rates compared to soil-based cultivation (PS1). At 40 days after planting (DAP), the daughter bulb weight of soilless cultivation (PS2) bulbs was more than that of the soil-based cultivation (PS1) counterparts. The bulbs showed accelerated growth and the rate of bulb production increased between 60 and 140 days after planting (DAP). [34,35] carried out research on the saffron replacement bulbs at a number of different phenological stages and obtained results that were consistent with these findings. This trend continues throughout the experiment and soilless cultivation (PS2) treatment outperformed soil-based cultivation (PS1) in terms of growth of daughter bulbs. However, end of the growing cycle (after 140 DAP) saw an exponential increase in the weight of the daughter bulbs in both the experimental treatments. This rise corresponded directly to the depletion of the nutritional reserves of the mother corms and foliage. The growth rate of bulbs for soilless cultivation (PS2) show a steeper and more rapid increase compared to soil-based cultivation (PS1). At the end of the observation period (at 200 DAP), PS2 bulbs demonstrated a higher final biomass compared to the PS1 bulbs. This indicates that saffron plants in soilless media have a faster growth rate and achieve higher biomass accumulation compared to those in soil, similar to the findings of [36]. In comparison to soil, the soilless medium that was used in the study demonstrated better aeration properties. The structure of soilless medium would have made it possible for there to be increased oxygenation around the root zone of the corms. Saffron corms must have access to a enough amount of oxygen in order to have healthy growth and development. Increased oxygenation in soilless media encourages the development of healthier root systems and the absorption of nutrients, which leads to the production of larger corms. Moreover, the fertigation was carefully planned so that it would deliver the optimal nutrient doze. Because of this carefully controlled nutrient environment, the saffron plants were provided with all the necessary nutrients in readily absorbable forms. Plants are able to absorb and make use of nutrients more effectively when they are provided with a nutrient supply that is properly balanced. This could have resulted in stronger and more vigorous plant growth. There is a possibility that the development of larger corms was helped along by the presence of a nutrient-rich environment in soilless medium. This indicates that saffron plants in soilless media have a faster growth rate and achieve higher biomass accumulation compared to those in soil. Our results are consistent with those reported by [37-40] for protected cultivation of saffron.

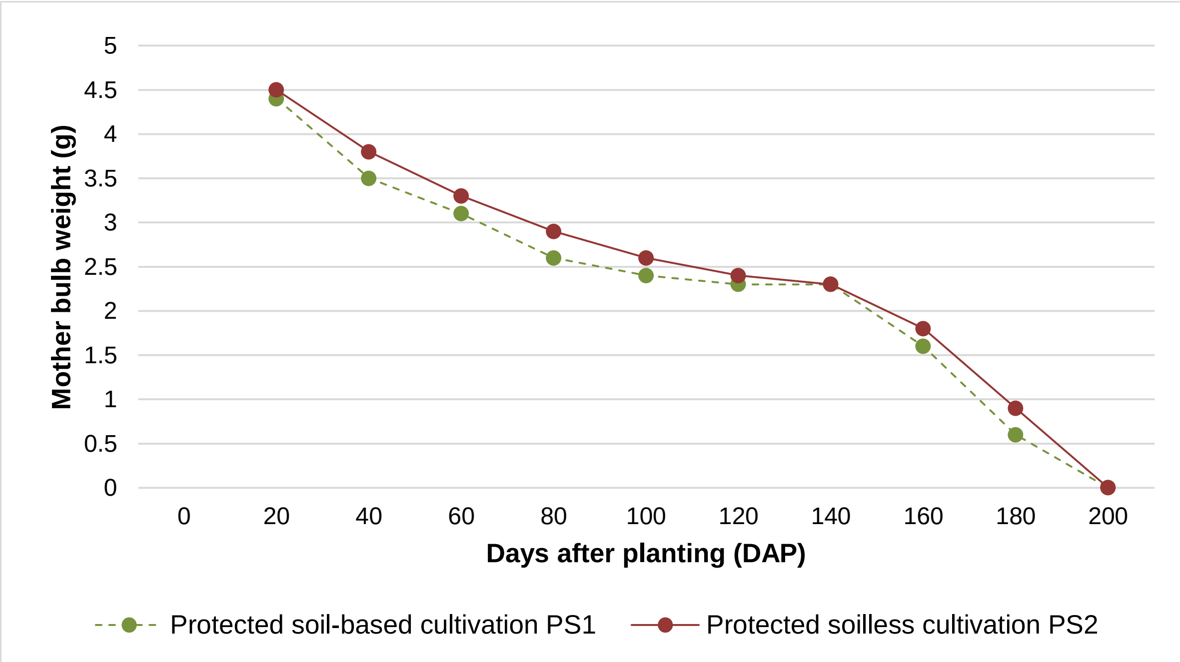

Fig. 3. Mother bulb weight changes during saffron growth cycle (26th October – 13th May)

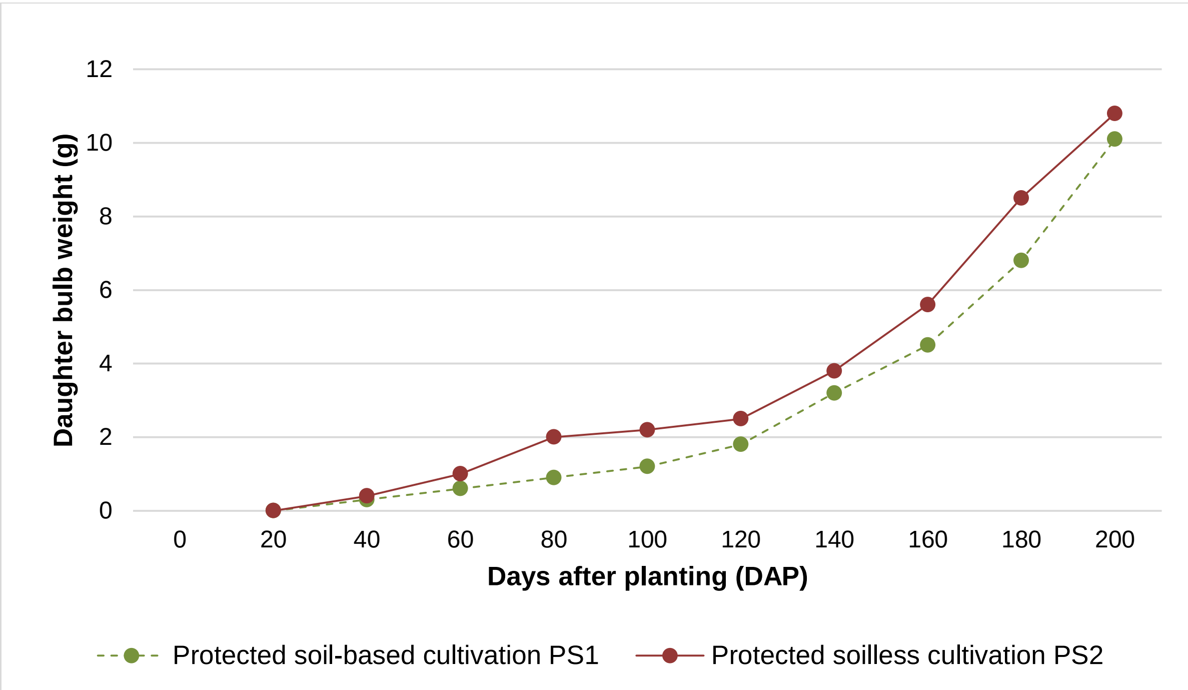

Fig. 4. Daughter bulb weight changes during saffron growth cycle (26th October – 13th May)

4. CONCLUSIONS

The use of soilless cultivation as a crop growing method may offer a solution to the problems that are encountered when saffron is traditionally produced in soil. This study explores the possibility of growing saffron under protected conditions in soilless growing media. The effect of soilless cultivation on the foliage, root, and bud growth trends have been studied. The results are compared to the protected soil-based cultivation, with a particular emphasis on the effect that the experimental treatments had on the phenology of saffron. The distribution of dry matter occurs in two distinct phases, as seen by the growth pattern of different saffron organs, including as foliage, roots, mother bulbs, and replacement bulbs, across the crop's numerous phenological stages. During the first phase of the partitioning, the majority of the biomass was allocated to the foliage and roots. During the next phase, however, the replacement bulbs received the largest share of the dry matter. Given that saffron can only be propagated through bulbs, any increase in the yield or improvement in the quality of the crop must be the result of simultaneous improvements in the bulbs. As a result, it is essential to have an understanding of the effects that the growing conditions can have on the performance of saffron bulbs. The dry weight of bulbs produced without soil was found to be significantly higher than that of bulbs grown in soil. According to the results of this study, protected soilless cultivation (PS2) is superior to protected soil-based cultivation (PS1), in terms of growth rate of various organs and biomass accumulation. The data suggests that saffron plants grown in soilless media had an environment that was more favorable and better nutrient availability, which resulted in greater growth and higher biomass production compared to saffron plants grown in soil. This contrasts with saffron plants grown in soil, which had an environment that was less favorable for growth and biomass accumulation. Based on our findings that saffron performed better in soilless media than in soil, it is reasonable to propose soilless cultivation for its production. Further research is needed to address the issue of growing media selection, nutrient requirements, and other aspects that will maximize the yields from the soilless method of cultivation.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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