Journal of Environmental Engineering and Landscape Management
ISSN 1648–6897 / eISSN 1822-4199
2023 Volume 31 Issue 1: 44–51
https://doi.org/10.3846/jeelm.2023.18487

THE POTENTIAL FOR USING DIFFERENT SUBSTRATES IN GREEN ROOFS

Handan CAKAR[1*], Ozlem AKAT SARACOGLU[1], Hulya AKAT[2], Cenk Ceyhun KILIC[1], Hakan ADANACIOGLU[3]

[1]Bayindir Vocational School, Ege University, Bayindir-Izmir, Turkey
[2]Ortaca Vocational School, Mugla Sitki Kocman University, Ortaca-Mugla, Turkey
[3]Department of Agricultural Economics, Faculty of Agriculture, Ege University, Bornova-Izmir, Turkey

Received 06 June 2022; accepted 09 November 2022

Highlights

- The lightest material among the substrates analysed in the study is loofah.
- The most successful material in terms of the minimization of the compaction in the planting layer is loofah.
- The most successful material in terms of temperature and moisture is perlite.
- Perlite has shown the highest success in terms of plant growth.
- Cocopeat has the highest water holding capacity among the substrates studied.
- The soil can not be used alone for the best performance while preparing the plant growing media.

Abstract. This research was carried out in Izmir-Turkiye and investigated the potential of using three different substrates (cocopeat, loofah and perlite) in the design of green roofs with succulents (*Crassula ovata*) in aim to improve their performance. In this research, four different groups (G_1: Soil-Cocopeat, G_2: Soil-Loofah, G_3: Soil-Perlite and G_4: Soil) were created according to the plant growing media used in the planting layer. The researchers conducted measurements of the drained irrigation water's EC (Electrical Conductivity) value, pH value and drainage amount, the plant growing media's temperature and moisture, the plant's height and leaf number, and the amount of subsidence in the planting layer. In line with the results obtained from the evaluations of the analyses, it is possible to say that perlite (G_3) offers more advantages than its alternatives in terms of many variables. However, according to the conclusive results, it has been understood that the use of a single type of substrate as plant growing media would not be sufficient to encourage the maximum performance of green roofs. To ensure that, considering the advantages of each substrate group, it is proposed that their combined use would be more beneficial.

Keywords: roof garden, vegetated roof, loofah, cocopeat, perlite, *Crassula ovata*.

Introduction

Several studies have been carried out to propose ways of reducing the effects of climate change, the symptoms of which we observe today, and preserving ecological balance. Among these studies, the ecosystem-based approach, green roof applications, have gained momentum in terms of ensuring the sustainability of ecological balance (Gülgün Aslan & Yazici, 2016). The aim of green roof designs, which are important elements of landscape architecture, has shifted from providing aesthetic pleasure to creating a component of urban ecology (Younis et al., 2020). As a result, different terms such as "roof garden", "vegetated roof" or "living roofs" have come to the fore today (Ekşi, 2014). Green roofs, which are classified as green space structures that offer important ecological benefits to cities, can be effective against the consequences of climate change, such as floods and overflows caused by heavy rains, high city temperatures, and atmospheric pollution (Dunnett & Kingsbury, 2008; Manso et al., 2021). At the same time, the vegetation in the green roofs can provide a living environment for birds and insects, clean the air, and positively improve the conditions of the habitat of all living things by cooling the air through evaporation (Wooster et al., 2022). Besides providing micro-climate control, green roofs can also reduce the wind speed and act as a sound insulation layer by absorbing sound waves (Rowe, 2011; Manso et al., 2021). In addition, green roofs improve aesthetic value,

*Corresponding author. E-mail: *handan.cakar@ege.edu.tr*

increase work efficiency, and encourage the development of social relations by providing people with alternative and special resting areas, especially in buildings used for tourism, work, education, and health services. Green roofs also increase the economic value of the buildings, and make them preferable (Erkul & Sönmez, 2014).

In green roof applications, the climate conditions of the region such as wind, solar radiation duration and intensity, temperature, precipitation, and structural conditions, such as the roof's load carrying capacity, slope and direction, are important factors. Besides the static structure of the building, other factors affecting the success of a green roof can be named as; the qualities and properties of the substrate used in the growing of plants and the design of the roof cover. The roof cover consists of different layers; the planting layer, filter, drainage, protection, water and heat insulation, and structural layer (Reyes et al., 2016; Korol et al., 2018; Cascone, 2019). It is highly important to ensure the waterproofing and thermal insulation of the roof cover as it is essential, but increases the green roof's installation cost and is challenging to prepare. The substrates examined in this study are materials that can be used in sufficient quantities for plants that grow in a limited area, can act as a buffer, do not carry disease-pests and weed seeds, and have high water holding capacity and nutrient contents. The pH value of the substrate may vary in relation to the requirements of the vegetation, but it should be between 6.0, and 8.5 and for turf substrates between 5.5 and 7.5 (Landscape Development and Landscaping Research Society e.V. [FLL], 2018).

The use of soil as a sole substrate in green roofs is not highly recommended due to several disadvantages (the clogging of the filter layer, spreading of weed seeds and the high cost of controlling, loss of porous structure due to soil compaction, etc.) (Calheiros & Stefanakis, 2021). Nonetheless, lightweight textured soil can be preferred, as well as soil combining high organic matter content (farmyard manure, compost, peat, decomposed sawdust or bark, cocopeat, etc.) and inorganic materials (perlite, volcanic tuff, pumice, rockwool, schist, vermiculite, etc.) in certain proportions (Aslanboğa, 1988; Ürgenç, 1990; Johnston & Newton, 1993; Ampim et al., 2010). In recent years, mushroom compost and sewage sludge have been included in these materials. However, sewage sludge requires careful handling due to its heavy metal concentration (Woolley & Kimmins, 2000). Components such as recycled waste materials and by-products from foundries or incinerators could potentially be used, but contaminant concentrations must be taken into consideration (Rowe, 2011). In the case of a wrong substrate choice, the consequences could be compaction, imbalances between water and air, asphyxia of the root apparatus, increased weight, reduction in drainage, and the alteration of nutrients (Cascone, 2019).

The roof load bearing capacity is an important factor when deciding the plant species that will be used in the green roof and the thickness of the planting layer. Intensive green roofs, those with more than 15 cm of planting layer, can host a variety of plants such as herbaceous perennials, grass, and even trees, if the roof has adequate structural support. On extensive green roofs with a planting layer depth of 15 cm or less, the shallow planting layers cannot sustain most plants except those particularly adapted to drought and extreme temperatures (Vandegrift et al., 2019).

Consistent with the FLL recommendations, the first accepted generalization is that succulent-dominated green roofs are well-suited to survive the extreme conditions of roofs and based on the many of the ecoregions investigated, they prefer shallow growing media, from 7 to 10 cm thickness. The second generalization is that herbaceous-dominated green roofs appear to need growing media more than 10 cm deep across most ecoregions (Dvorak & Volder, 2010). Cascone (2019) has proposed that generally, the growing media weight of extensive roofs varies between 12–14 kg m^{-2} with a thickness of 8 cm, and of intensive roofs it is around 600 kg m^{-2} with a thickness of 50–60 cm.

Accordingly, this study has preferred to investigate the design of an extensive green roof by using succulents as they will not grow extensively tall, are drought resistant, and have low nutrient requirements. This study has aimed to demonstrate the potential use of three different substrates (mixed with soil; cocopeat, loofah, and perlite) in the green roofs.

1. Materials and methods

The research was carried out at Ege University Bayındır Vocational School in Izmir- Turkiye during the 3-month long summer period (from June 2021 to September 2021) as an open field pot experiment.

1.1. Plant materials

The plant species that was used to achieve the research target was *Crassula ovata*, which belongs to the succulent (fleshy-leaved) plant family and is suitable for extensive green roof designs. The plant seedlings that were chosen had reached a homogenous size, demonstrated healthy development, had 15 leaves, were 10 cm long, and did not show branching. The plants of the family Crassulaceae are often used in green roofs designs due to their low irrigation requirements and adaptability to sunny environments. The use of plants with low irrigation requirements is all the more advantageous in places where water availability is limited (Chagolla-Aranda et al., 2017). Thus, *Crassula ovata* species was chosen for the study due to its capability to develop quickly as a plant material and because the plant's oval leaves would provide easier measurement during the research.

1.2. Substrates

For the green roof designs in the research, 4 different groups (G_1, G_2, G_3 and G_0) were formed according to the plant growing media used in the planting layer. Kadıoğlu and Canbolat (2019), determined that the mixing ratio of perlite with soil of 25%:75% has higher water holding capacity than other mixing media. In this study, the substrate ratios of the plant growing media used in the groups were determined as 25%:75%. The substrate contents of the plant growing media used in these groups are as follows:

- G_1: The substrate used was S_{75}:Co_{25} and consisted of soil (S) and cocopeat (Co) in a volumetric ratio of 75:25.
- G_2: The substrate used was S_{75}:Lo_{25} and consisted of soil (S) and loofah (Lo) in a volumetric ratio of 75:25.
- G_3: The substrate used was S_{75}:Pe_{25} and consisted of soil (S) and perlite (Pe) in a volumetric ratio of 75:25.
- G_0: The substrate used was S_{100} and consisted of soil (S) in a volumetric ratio of 100:- (Control group).

The bulk density (g cm^{-3}) and the visuals of the substrates featured in the study can be found in Figure 1.

Substrates	Cocopeat	Loofah	Perlite	Soil
				
g cm^{-3}	0.19	0.04	0.24	1.33

Figure 1. The bulk density and visuals of the substrates used in the experiment

The physical and chemical properties of the substrates in the research are as follows:

- Cocopeat: EC < 0.5 ds m^{-1}, pH 5.5–7;
- Perlite: EC < 0.0 ds m^{-1}, pH 6.5–7.5, particle size < 3.0 mm;
- Soil: Texture loamy sand, pH 7.79, EC 0.12 ds m^{-1}, organic matter content 0.45%, nitrogen content 0.022%.

Loofah: Any literature and research on the use of loofah (*Luffa cylindrica*) as a substrate could not be found. Thus, the results obtained from this research could potentially contribute to the literature regarding the use of loofah as a substrate in green roof applications. The fibre part obtained from the matured dried fruit of the loofah plant was used in this study. The Loofah was divided into small pieces (3–5 mm) with the help of scissors before being mixed homogeneously into the soil.

1.3. Experimental design

The research area was designed in 3 replicates in accordance with the "random blocks experimental design". Transparent plastic pots with a diameter of 15 cm and a drainage outlet at the bottom were used as green roof models in the study area. Drainage containers with a volume of 1.5 litres were placed under the pots, which were connected to a drainage outlet preventing any possible leaks. Extensive green roof design principles were applied during the preparation process of the pots (Reyes et al., 2016; Korol et al., 2018; Cascone, 2019). To evaluate the potential of the substrates within the scope of this research, the pot arrangement in the experiment featured the planting layer, filter, and drainage layers, after each was considered sufficient. In this regard, the pebbles were placed in all the pots at a height of 5 cm first.

In green roof designs, a filtering layer should be used between the drainage and planting layer (Özdemir & Altun, 2010; Seçkin & Seçkin, 2016). Thus, the geotextile product named Polypropylene fabric (95 g m^{-2}), also known as ground cover fabric in landscaping, was chosen as the filtration material. Accordingly, the polypropylene fabric was laid on the pebbles as a filtration material in all the pots.

Dvorak and Volder (2010) demonstrated that succulents performed best in the growing media at a depth of 7–10 cm. Cascone (2019) stated that generally for extensive green roofs, the growing media should have a thickness of 8 cm. Therefore, the depth of planting layer was an average of 8 cm. The four separately prepared plant growing medias were laid on the polypropylene fabric at a depth of 8 cm to form the planting layers. No nutrient solution was added to the plant growing media as the plants did not require fertilization throughout the research period.

After adding the plant growing media into the pots, *Crassula ovata* was planted as one plant per pot.

The sample trial pot created for this study based on extensive green roof design principles is given in Figure 2.

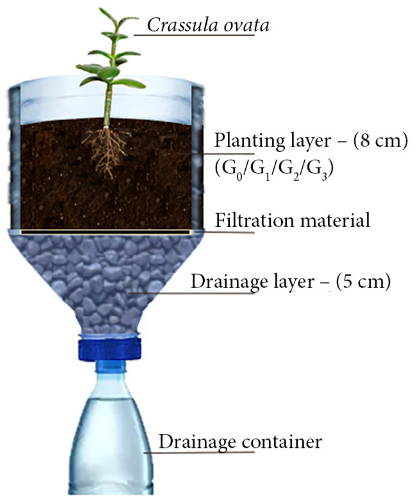

Figure 2. Cross-section of the sample pot used in study

1.4. Measurments

The study area, which is under the conditions of a climate with dry summers, received no precipitation in throughout this research process. The plants were watered under careful control. In the irrigation process, which was initiated after the planting, 800 mL of water per plant was used. The pots were watered twice a week at 9:00 a.m. with the use of a measuring cup to ensure they would receive the same amount (400 mL day^{-1}). The measurements of the plant growing media's temperature and moisture were carried out 24 hours after the irrigation process was completed. These measurements were made at a depth of 5 cm from the surface, taking into consideration the plant root depth in the pot. A hand-held digital thermometer (TempLog Digital Thermometer) was used for temperature measurements, and a pot type moisture meter was used for moisture measurement.

Following the completed irrigation processes, the drained irrigation water collected in the lidded drainage containers was measured by volume every week before being removed from the system. After the determination of the drainage amounts, the EC (Electrical conductivity) value and pH value measurements were carried out in the drained water once a week. An EC meter (WTW, Cond 330i conductivity meter set) was used for the EC value measurements and a pH meter [WTW, pH 3210 (330i) pH meter set (portable)] was used for pH value measurements.

To determine the amount of subsidence in the planting layer, which was designed with a depth of 8 cm at the beginning of the study, the height of the planting layer was once again measured at the end of the experiment.

In order to examine the effect of the 4 groups, (differing based on the substrates of their plant growing media) on the plant's growth, plant height (cm) and leaf number (number) measurements were carried out once a week to observe the plants' physical properties.

1.5. Statistical analyses

Various statistical analyses were applied to test whether the factors examined in this study differ in relation to substrates. The factors examined were EC value (μS cm^{-1}), pH value, drainage amount (mL), in-pot temperature (°C), in-pot moisture (%), plant height (cm), number of leaves (number), and subsidence (mm) in the planting layer. Since the data can be variable, the Kolmogorov-Smirnov test was used to conduct a normal distribution test. While analysis of variance (one-way anova) was applied to the variants demonstrating normal distribution, Kruskal-Wallis was applied to those that did not. The data in this study were analysed using the IBM SPSS Statistics (v21) software.

1.6. Hypotheses

The results obtained from this study aimed to determine the substrate that offers the most suitable conditions, among those examined in the study, to be used in the extensive green roofs. With this research, some hypotheses have been proposed regarding the substrates that could be used in extensive green roofs. These hypotheses are stated below:

H1: In extensive green roofs, EC value (μS cm^{-1}), pH value, drainage amount (mL), in-pot temperature (°C), in-pot moisture (%), plant height (cm), number of leaves (number), and the amount of subsidence (mm) in the planting layer vary based on the performance of different types of substrates.

H2: To achieve the best performance in extensive green roofs, it is not sufficient to use a single type of substrate as plant growing media.

2. Results

2.1. EC value

The descriptive statistical results of the EC (Electrical conductivity) measurements, that were conducted on the groups with the differing substrates analysed in this study, can be found on Table 1. According to this, the highest salinity (EC) values within the irrigation water drained from the planting layer were spotted in the group (G_1), in which cocopeat was used as the substrate. The lowest salinity values were found in the control group (G_0), followed by the group using loofah as substrate (G_2). Due to the normal distribution of the data, one-way ANOVA analysis was used to analyse the statistical differences between the substrates in terms of salinity (EC) values. According to the results obtained from the analysis, a significant statistical difference was found between the substrates in terms of salinity (EC) values at the 5% significance level ($F = 4.096$; $p = 0.007$).

Table 1. The salinity (EC) values (μS cm^{-1}) of substrates

Substrates	n	Mean	Minimum	Maximum	Std. Deviation
G_1	9	444.54	275.00	655.00	100.71310
G_2	9	415.92	256.00	670.00	125.61636
G_3	9	424.75	254.00	706.00	115.23709
G_0	9	397.33	242.00	803.00	124.96457

2.2. pH value

The descriptive statistical results that were obtained by the pH measurement of the groups featuring the differing substrates are given in Table 2. Accordingly, the lowest pH value of 9.23 was obtained from the loofah group (G_2). This was followed by the cocopeat group (G_1) with 9.35. The highest values were found in the perlite group (G_3) and control group (G_0), which were close to each other, with 9.51 and 9.56 respectively. According to the results of one-way ANOVA analysis, no statistically significant difference was found between the substrates in terms of pH values ($F = 1.485$; $p = 0.219$).

Table 2. pH values according to substrates

Substrates	n	Mean	Minimum	Maximum	Std. Deviation
G_1	9	9.35	8.57	10.46	0.49426
G_2	9	9.23	8.50	10.29	0.50118
G_3	9	9.51	8.81	10.69	0.60909
G_0	9	9.56	8.75	10.74	0.65400

2.3. Drainage amount

The drainage amount measured from the pot drainage outlets of the groups featuring the differing substrates analysed in this study are shown in Table 3. According to these measurements the lowest drainage amount was found in the cocopeat group (G_1) with 185.83 mL. This was followed by perlite (G_3) with 217.63 mL, loofah (G_2) with 257.42 mL, and control group (G_0) with 342.54 mL.

Because the data did not demonstrate normal distribution, the Kruskal-Wallis test was applied to determine the difference in the measured drainage amounts according to the substrates. According to the test results obtained, a statistically significant difference was found between the substrates in terms of drainage amounts (Chi-Square: 50.801; p = 0.000).

Table 3. Measured drainage amounts according to substrates (mL)

Substrates	n	Mean	Minimum	Maximum	Std. Deviation
G_1	9	185.83	130.00	270.00	45.84915
G_2	9	257.42	135.00	373.00	68.29407
G_3	9	217.63	108.00	350.00	63.28735
G_0	9	342.54	204.00	460.00	70.82126

2.4. In-pot temperature

The air temperature readings recorded during the study were between min. 34.14 °C – max. 46.08 °C. The average temperature values measured in the pot according to the groups with the differing substrates are given in Table 4. According to the findings, the lowest temperature value among the results was spotted in the perlite group (G_3) with 34.10 °C. Besides that, the values measured in the cocopeat group (G_1) and loofah group (G_2), being 34.32 °C and 34.92 °C respectively, were close to the values observed in the perlite group (G_3). It was determined that the average temperature value measured in the control group (G_0) was 36.09 °C, which was the highest compared to the other groups. According to the Kruskal-Wallis test results, a statistically significant difference was found between the substrates in terms of temperature values (Chi-Square: 9.303; p = 0.026).

Table 4. Average temperature values measured by substrates (°C)

Substrates	n	Mean	Minimum	Maximum	Std. Deviation
G_1	9	34.32	28.30	41.10	4.40773
G_2	9	34.92	28.50	41.20	3.96799
G_3	9	34.10	28.20	41.30	4.42879
G_0	9	36.09	29.00	43.00	4.18630

2.5. In-pot moisture

The relative humidity readings recorded during the study were between min. 15.0% – max. 39.12%. The average moisture content values measured in the pots of the groups with the differing substrates are given in Table 5. According to these numbers, the highest moisture content value among the substrates was determined as 40.58% in the perlite group (G_3). This was followed by the cocopeat group (G_1) with 39.54%, the loofah group (G_2) with 36.08% and the control group (G_0) with 26.21%. As it can be understood from these values, a very low moisture value was observed in the control group, in which there was no intervention. As the data was not normally distributed, the Kruskal-Wallis test was applied to examine the difference in the moisture content values according to the substrates. According to the test results obtained, a statistically significant difference was found between the substrates in terms of moisture values (Chi-Square: 16.875; p = 0.001).

Table 5. Average moisture content values according to substrates (%)

Substrates	n	Mean	Minimum	Maximum	Std. Deviation
G_1	9	39.54	22.00	66.00	12.23317
G_2	9	36.08	15.00	54.00	11.16250
G_3	9	40.58	18.00	62.00	12.52794
G_0	9	26.21	12.00	42.00	10.57881

2.6. Plant height

The average plant height measurements of the groups with the differing substrates analysed in the study are given in Table 6. According to these, the highest value of plant height was determined as 14.04 cm in the perlite group (G_3). This was followed by the control group (G_0) with 12.00 cm, the cocopeat group (G_1) with 11.80 cm, and the loofah group (G_2) with 10.94 cm. Since the data did not demonstrate normal distribution, the Kruskal-Wallis test was applied to determine the difference in plant height values measured according to the substrates. According to the test results, a statistically significant difference was found between the substrates in terms of plant height values (Chi-Square: 25.262; p = 0.000).

Table 6. Average plant heights by substrates (cm)

Substrates	n	Mean	Minimum	Maximum	Std. Deviation
G_1	9	11.80	10.00	14.00	1.21386
G_2	9	10.94	10.00	12.30	0.63095
G_3	9	14.04	10.00	18.00	2.67938
G_0	9	12.00	10.00	15.80	1.69090

2.7. Number of leaves

The recorded leaf numbers of the groups with the different substrates can be seen in Table 7. According to the findings, perlite group (G_3) and control group (G_0) had the highest number of leaves per plant with 29.96. This was followed by the cocopeat group (G_1) with 26.21. The lowest number of leaves per plant was determined as 18.67

in the loofah group (G_2). According to the Kruskal-Wallis test results, a statistically significant difference was found between the substrates in terms of leaf number values (Chi-Square: 25.463; p = 0.000).

Table 7. Average number of leaves by substrates (number)

Substrates	n	Mean	Minimum	Maximum	Std. Deviation
G_1	9	26.21	15.00	40.00	7.12606
G_2	9	18.67	15.00	30.00	4.39037
G_3	9	29.96	15.00	48.00	10.42355
G_0	9	29.96	15.00	48.00	10.42355

2.8. Amount of subsidence in the planting layer

The amount of subsidence observed in the pots of the groups with the differing substrates analysed in the study are given in Table 8. According to these values, the group demonstrating the least subsidence was the loofah group (G_2) with 3.83 mm. This was followed by the perlite group (G_3) with 4.67 mm, the cocopeat group (G_1) with 5.17 mm, and the control group (G_0) with 11.83 mm. As it can be understood from these findings, the average amount of subsidence was the highest in the control group (G_0) with only soil. According to the Kruskal-Wallis test results, a statistically significant difference was found between substrates in terms of subsidence values (Chi-Square: 26.094; p = 0.000).

Table 8. Average amount of subsidence in the planting layer according to the substrates (mm)

Substrates	n	Mean	Minimum	Maximum	Std. Deviation
G_1	9	5.17	4.00	6.00	1.04083
G_2	9	3.83	3.50	4.00	0.28868
G_3	9	4.67	4.00	5.00	0.57735
G_0	9	11.83	7.50	15.50	4.04145

3. Discussions

The data obtained during the study of the groups with differing substrates are summarized and given in Table 9 to demonstrate the substrates' superior properties.

Among the groups with the differing substrates analysed in this study, the lowest EC value was observed in the loofah group (G_2) following the control group (G_0). It is known that the growth and development of plants are negatively affected by the high EC value since it indicates the presence of high levels of soil salinity (Ekmekçi et al., 2005). Thus, apart from the control group (G_0), the loofah group (G_2) was the best option in terms of salinity drainage among the substrates.

When the data was analysed in terms of the amount of drainage, the lowest amount of drainage among the groups with the differing substrates was observed in the cocopeat (G_1) group, followed by the perlite group (G_3). It is known that the amount of drainage water should be kept at a minimum to reduce the negative effects of excessive drainage on the environment, and minimize the cost of fertilizer (Başar, 2000). For this reason, it was concluded that the cocopeat group (G_1) was better than the alternative substrates in terms of drainage amount, while the control group (G_0) should not be preferred due to the very high drainage amount.

When the data was examined in terms of pot temperature, close values between the substrates were observed, except for the control group (G_0), as its pot temperature was considered high. As is known, the planting layer's heat storage feature becomes beneficial in the summer due to the cooling effect of the plant layer on the surface, which also decreases the access of thermal load and reduces the cooling energy needs of buildings (Liu, 2004; Gaffin et al., 2006; Saiz et al., 2006; Ayçam & Kınalı, 2013). It has been observed that the addition of the substrates analysed in this research to the plant growing media has a positive impact since it protects the planting layer from high temperature, and hence, the building as well.

When the data was analysed in terms of the in-pot moisture, close values were observed among the substrates analysed in the study, except for the control group (G_0) as the soil moisture of that group was low. It is known that plants initially get stressed due to the decrease in the amount of water in the soil and if the moisture decrease continues, they ultimately die (Tamsa, 2013). It has been concluded that adding the analysed substrates to the plant growing media would contribute positively in terms of moisture retention for plant roots.

The highest results for the number of leaves and plant height were observed in the perlite group (G_3) among the groups with the differing substrates analysed in the study. While the control group (G_0) showed the same success as the perlite group (G_3) according to the number of leaves, it ranked second, behind the perlite group (G_3), in terms of plant height. It is believed that the results obtained in terms of plant growth will vary according to the needs of the different plant species that can be used in extensive green roof designs. In this study where the *Crassula ovata* plant was used, the plant growth in all groups was considered sufficient and it was concluded that all the substrates included in the study can be used as plant growing media in extensive green roof designs.

When the data on the amount of subsidence in the planting layer was examined, the best result in terms of the amount of subsidence was observed in the loofah group (G_2) with the least amount, while the highest amount of subsidence was seen in the control group (G_0). Subsidence is a degradation process related to compression and occurs when the structural form of the planting layer gets disrupted because of rainfall or external mechanical forces. Compression in the planting layer may cause negativities in the physical and hydrological properties of the environment, but also lead to the physiological deterioration of plants, affect the plant's balance and its growth hormones, and limit its intake

Table 9. Ordinal distribution of factors compared by substrates (1: best; 4: worst)

	EC	pH	Drainage	Temp.	Moist.	Plant height	Number of leaves	Subsidence
Substrates								
G_1	4	2	1	2	2	3	3	2
G_2	2	1	3	3	3	4	4	1
G_3	3	3	2	1	1	1	1	3
G_0	1	4	4	4	4	2	2	4
Statistically significant difference among groups	yes	no	yes	yes	yes	yes	yes	yes

of nutrients (Turgut, 2012). According to the results obtained, regarding the addition of the researched substrates to the plant growing media, it has been observed that they significantly contribute to the reduction of the amount of subsidence in the planting layer.

The data obtained by the groups with the differing substrates analysed in the study are evaluated on a scale from 1 to 4 and summarized in Table 9. Regarding all the data obtained in terms of the substrates included in the experiment, the best case was evaluated as 1 point and the worst case 4 points. In the evaluation carried out, those that demonstrated a statistically significant differences in terms of the studied factors were taken into account. According to this, it was understood that the best option among the substrates in terms of EC values was the control group (G_0). Since there was no statistically significant difference between the substrates in terms of pH values, this factor was not taken into account. It was determined that the group with the best water holding capacity according to the measured drainage amount was cocopeat (G_1). On the other hand, the perlite group (G_3) turned out to be the best option in terms of in-pot temperature, in-pot moisture, plant height and number of leaves per plant. In regard to the amount of subsidence in the planting layer, the best result was observed in the loofah group (G_2). According to all the results, it is possible to say that perlite (G_3) offers more advantages than the alternative substrates in terms of many variables. In addition, in line with the hypotheses of the study, the performance of the groups according to the substrate types has varied regarding "EC value", "pH value", "drainage amount", "in-pot temperature", "in-pot moisture", "plant height", "number of leaves" and "the amount of subsidence in the planting layer".

It is believed that the use of a single type of substrate as plant growing media would not be sufficient in terms of ensuring the best performance of extensive green roofs, and it would be more beneficial to consider the advantages that each substrate group demonstrated in the aforementioned subcategories.

Conclusions

Green roofs and green areas are an important indicator of the quality of urban life. They establish a connection between nature and the city's nostalgia for green spaces, and they incorporate nature within the city. This study has aimed to provide information regarding the ecosystem-based approach of green roofs and discuss the potential use of the researched substrates in extensive green roofs. In this regard, recommendations were made according to the results obtained from the study.

One of the most important aspects in the design of extensive green roofs is the weight of the roof covering layer, which should be appropriate for low load-bearing roofs. In order to reduce the weight on the roof, the lightest possible substrates should be preferred within the planting layer. In this regard, it has been observed that the lightest material among the substrates analysed in the study is loofah, which could be a good choice. In addition, loofah was chosen as the substrate with the highest performance among the others in this study regarding the minimization of the subsidence in the planting layer. Since there is no existing literature on the use of loofah as a substrate, it is proposed that the results obtained from this study contribute to the literature on the use of loofah as a substrate in green roof applications.

It is impossible to determine a single universal green roof substrate that could be preferred in all green roofs since its effects could change based on the green roof's design, climate conditions and geographical location, ecological suitability etc.

However, within the conditions that the research was carried out; although loofah has ranked behind the other substrates in terms of plant growth, it is a light material and creates a strong resistance against the substrate shrinkage that may occur in the planting layer. In addition to its success in in-pot temperature and moisture, perlite has shown the highest success in terms of plant growth among all the substrates included in the study. Cocopeat has the highest water holding capacity among the substrates studied.

To achieve the best performance in extensive green roofs, it is recommended not to use the soil alone while preparing the plant growing media but to combine it with more than one substrate type, after considering the success rate of the substrates or according to the type of substrates.

It is believed that the results obtained from this study will benefit the relevant literature, initiate different studies, and shed light on future research.

References

Ampim, P. A. Y., Sloan, J. J., Cabrera, R. I., Harp, D. A., & Jaber, F. H. (2010). Green roof growing substrates: Types, ingredients, composition and properties. *Journal of Environmental Horticulture*, *28*(4), 244–252. https://doi.org/10.24266/0738-2898-28.4.244

Aslanboğa, İ. (1988). *Ege Bölgesi iklim koşullarında çatı bahçesi yapımında kullanılabilecek yapısal ve bitkisel materyalin seçimi* üzerine *araştırmalar*. Bilgehan Basımevi, Bornova-İzmir.

Ayçam, İ., & Kınalı, M. (2013). Ofis binalarında yeşil çatıların ısıtma ve soğutma yüklerine olan etkilerinin analizi. *Tesisat Mühendisliği*, *135*, 26–34.

Başar, H. (2000). Bazı topraksız yetiştiricilik yöntemlerinin karşılaştırılması. *Anadolu Ege Tarımsal Araştırma Enstitüsü Dergisi*, *10*(2), 169–182.

Calheiros, C. S. C., & Stefanakis, A. I. (2021). Green roofs towards circular and resilient cities. *Circular Economy and Sustainability*, *1*, 395–411. https://doi.org/10.1007/s43615-021-00033-0

Cascone, S. (2019). Green roof design: State of the art on technology and materials. *Sustainability*, *11*(11), 3020. https://doi.org/10.3390/su11113020

Chagolla-Aranda, M. A., Simá, E., Xamán, J., Álvarez, G., Hernández-Pérez, I., & Téllez-Velázquez, E. (2017). Effect of irrigation on the experimental thermal performance of a green roof in a semi-warm climate in Mexico. *Energy and Buildings*, *154*, 232–243. https://doi.org/10.1016/j.enbuild.2017.08.082

Dunnett, N., & Kingsbury, N. (2008). *Planting green roofs and living walls* (2nd ed.). Timber Press Inc.

Dvorak, B., & Volder, A. (2010). Green roof vegetation for North American ecoregions: A literature review. *Landscape and Urban Planning*, *96*(4), 197–213. https://doi.org/10.1016/j.landurbplan.2010.04.009

Ekmekçi, E., Apan, M., & Kara, T. (2005). Tuzluluğun bitki gelişimine etkisi. *OMÜ Ziraat Fakültesi Dergisi*, *20*(3), 118–125.

Ekşi, M. (2014). Çatı bahçesi kavramı ve terim kullanımı üzerine bir değerlendirme. *Avrasya Terim Dergisi*, *2*(2), 26–35.

Erkul, E., & Sönmez, A. (2014). Çevre duyarlı mimarlık: Yeşil çatı sistemleri çevre etkileri. *Mimarlık Dergisi*, *375*, 52–58.

Gaffin, S., Rosenzweig, C., Parshall, L., Hillel, D., Eichenbaum Pikser, J., Greenbaum, A., Blake, R., Beattie, R., & Berghage, R. (2006, May 11–12). *Quantifying evaporative cooling from green roofs and comparison to other land surfaces* [Conference presentation]. The Fourth Annual Greening Rooftops for Sustainable Communities Conference Awards and Trade Show, Boston.

Gülgün Aslan, B., & Yazici, K. (2016). Yeşil altyapı sistemlerinde mevcut uygulamalar. *Ziraat Mühendisliği*, (363), 31–37.

Johnston, J., & Newton, J. (1993). *Building green: A guide to using plants on roofs, walls and pavements.* London Ecology Unit.

Kadıoğlu, B., & Canbolat, M. Y. (2019). Organik ve inorganik materyallerin ince bünyeli toprağa ilavesi ile hazırlanan yetişme ortamlarının hidrofiziksel özellikleri. *Atatürk Üniversitesi Ziraat Fakültesi Dergisi*, *50*(2), 107–114. https://doi.org/10.17097/ataunizfd.453748

Korol, O., Shushunova, N., & Shushunova, T. (2018). Innovation technologies in Green Roof systems. *MATEC Web of Conferences*, *193*(4), 04009. https://doi.org/10.1051/matecconf/201819304009

Landscape Development and Landscaping Research Society e.V. (2018). *Green roof guidelines: Guidelines for the planning, construction and maintenance of green roofs.* Bonn, Germany.

Liu, K. (2004). Engineering performance on rooftop gardens through field evaluation. *Journal of Roof Consultants Institute*, *22*(2), 4–12.

Manso, M., Teotónio, I., Silva, C. M., & Cruz, C. O. (2021). Green roof and green wall benefits and costs: A review of the quantitative evidence. *Renewable and Sustainable Energy Reviews*, *135*, 110111. https://doi.org/10.1016/j.rser.2020.110111

Özdemir, E., & Altun, M. C. (2010, Nisan 15–16). Bitkilendirilmiş *çatı* sistemi tasarımı için bir kontrol listesi *önerisi*. In *5. Ulusal Çatı ve Cephe Sempozyumu*, Dokuz Eylül Üniversitesi Mimarlık Fakültesi, Buca-İzmir. http://catider.org.tr/pdf/sempozyum5/Semp%205%20Bildiri%2022.pdf

Reyes, R., Bustamante, W., Gironás, J., Pastén, P. A., Rojas, V., Suárez, F., Vera, S., Victorero, F., & Bonilla, C. A. (2016). Effect of substrate depth and roof layers on green roof temperature and water requirements in a semi-arid climate. *Ecological Engineering*, *97*, 624–632. https://doi.org/10.1016/j.ecoleng.2016.10.025

Rowe, D. B. (2011). Green roofs as a means of pollution abatement. *Environmental Pollution*, *159*(8–9), 2100–2110. https://doi.org/10.1016/j.envpol.2010.10.029

Seçkin, Y. P., & Seçkin, Y. Ç. (2016, Haziran 2–3). Mimari tasarımda yeşil *çatıların* gelişimi. In 8. *Ulusal Çatı ve Cephe Sempozyumu*, Mimar Sinan Güzel Sanatlar Üniversitesi, Fındıklı- İstanbul. http://catider.org.tr/pdf/sempozyum8/06-MIMARI-TASARIMDA-YESIL-CATILARIN-GELISIMI.pdf

Saiz, S., Kennedy, C., Bass, B., & Pressnail, K. (2006). Comparative life cycle assessment of standard and green roofs. *Environmental Science and Technology*, *40*, 4312–4316. https://doi.org/10.1021/es0517522

Tamsa, H. K. (2013). *Sürekli solma noktasının tayininde yeni bir yaklaşım: difüzyon- toprak nem ilişkisi*. Namık Kemal Üniversitesi Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi, Tekirdağ.

Turgut, B. (2012). Ormanlık alanlarda toprak sıkışması sorunu. *SDÜ Orman Fakültesi Dergisi*, *13*, 66–73.

Ürgenç, S. (1990). *Genel plantasyon ve ağaçlandırma tekniği*. İstanbul Üniversitesi, Fakülte (Orman), Istanbul.

Vandegrift, D. A., Rowe, D. B., Cregg, B. M., & Liang, D. (2019). Effect of substrate depth on plant community development on a Michigan green roof. *Ecological Engineering*, *138*, 264–273. https://doi.org/10.1016/j.ecoleng.2019.07.032

Woolley, T., & Kimmins, S. (2000). *Green building handbook: Vol. 2. A guide to building products and their impact on the environment* (1st ed.). Routledge.

Wooster, E. I. F., Fleck, R., Torpy, F., Ramp, D., & Irga, P. J. (2022). Urban green roofs promote metropolitan biodiversity: A comparative case study. *Building and Environment*, *207*(A), 108458. https://doi.org/10.1016/j.buildenv.2021.108458

Younis, A., Zulfiqar, F., Ramzan, F., Akram, A., Wright, S. R., Farooq, A., Ahsan, M., & Sagu, A. H. (2020). Roof top gardening, a solution for landscape enhancement in urban areas: A case study of Faisalabad, Pakistan. *Pakistan Journal of Agricultural Sciences*, *57*(2), 333–337.