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The Growth and Qualitative Traits of Eighteen Ornamental Cover Plants in the Climatic Conditions of Gorgan, Iran

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Abstract

Given the deficiency of water resources in many Iranian cities and the substantial water usage by lawns, exploring the feasibility of reducing lawn areas and expanding green areas with planting cover plants is a rational approach to achieving sustainable green space. Cover plants offer a more varied and natural visual appeal than grasses. An essential consideration in green space design is selecting plants that respond well to seasonal changes in different climates. The present study aimed to evaluate 18 cover plants in the climatic conditions of Gorgan, Iran, over the course of a year (four seasons). The traits measured included appearance quality, chlorophyll a, b, and total, carotenoid content, and plant growth percentage. The comparison of data means indicated that the highest and lowest growth rates throughout the four seasons were observed in *Carpobrotus acinaciformis* and *Festuca ovina*, respectively. *Carpobrotus acinaciformis* exhibited the highest levels of chlorophyll a, b, and total. *Alternanthera bettzickiana* showed the highest carotenoid content in its leaves, closely followed by *Frankenia thymifolia*. The best visual quality was for *Osteospermum ecklonis* in spring, followed by *Frankenia thymifolia*, *Plectranthus australis*, and *Lysimachia nummularia*. The research revealed that, out of the 18 cover crops examined, the most suitable species for the urban green spaces of Gorgan under full sunlight and with no shading are *Frankenia thymifolia*, *Osteospermum ecklonis*, *Liriope muscari*, *Sedum reflexum*, *Ruellia tweediana*, *Carpobrotus acinaciformis*, and *Armeria maritima*. Additionally, plants like *Cerastium tomentosum*, *Phalaris arundinacea*, and *Lysimachia nummularia*, which exhibited yellowing and diminished growth and appearance quality due to the intense summer light in the summer, are likely to thrive in Gorgan's urban green spaces if they are cultivated in shaded areas.

Keywords: Climate, Ground cover, Green spaces, Landscape.

INTRODUCTION

Given the deficiency of water resources in many Iranian cities and the substantial water usage by lawns, exploring the feasibility of reducing lawn areas and expanding green areas with planting cover plants is a rational approach to achieving sustainable green space (Mushtaqian and Staki, 2015). However, cover plants vary in their water requirements, depending on their genus and species. In a study on six *Sedum* species, Shooshtarian *et al.* (2011) concluded that after nine irrigation cycles, the chlorophyll content was higher in *S. lydium, S. acre,* and *S. spurium* than in *S. spectabile, S. album,* and *S. hybridium.* Furthermore, McKeown *et al.* (2023) observed that Wedelia, as a cover plant, exhibited superior coverage and growth rates than Liriope at the irrigation intervals of 5, 9, 13, and 18 days.

Many ornamental cover plants are perennials and do not need replanting each year, thus reducing labor costs (Marble *et al.*, 2017). Additionally, some cover plants can absorb heavy metals. It has been reported that *Armeria* is tolerant of heavy metal accumulation in its roots and leaves (Olko *et al*., 2008).

Cover plants contribute to urban aesthetics, purify the air by filtering dust and pollutants, prevent overheating and desiccation of the environment, and play a crucial role in maintaining air freshness and reducing various forms of environmental pollution. They also help prevent extreme weather conditions, such as destructive storms, intense heatwaves, and severe droughts, while controlling weed growth and minimizing soil erosion (Zarei *et al*., 2018; Amoroso *et al*., 2009; Foo *et al*., 2011).

Humans have an innate appreciation for beauty and enjoy it. In this context, the natural colors of plants are far more effective than man-made hues. Indeed, the color of a plant is the first characteristic that draws attention. Owing to their diverse colors, cover plants offer a more varied and natural visual appeal than grasses Along highways, we often encounter steep slopes with unappealing landscapes that can be transformed by planting resilient and adaptive cover plants into a vibrant, natural, and aesthetically pleasing environment (Rezaei and Zabihi, 2015).

Many plants undergo various transformations with changing seasons and weather patterns. Cover plants are no exception. An essential consideration in green space design is selecting plants that respond well to seasonal changes in different climates. A study of 19 cover plants identified *Sedum spurium* and *Thymus praecox* as suitable choices for the urban green spaces of Trabzon, Turkey (Acar and Var, 2001). Esmaeili *et al.* (2017) investigated five cover plants, including *Oxalis brasiliensis* L., *Trifolium repen*s L., *Phyla nodiflora* L., *Frankenia thymifolia* Desf., and *Vinca minor* L., in Shiraz's climate over four seasons and found that the plants exhibited distinct responses across the four seasons. For instance, the catalase enzyme activity was the highest among the studied plants in summer, and the proline content was significantly higher in *Frankenia thymifolia* than in the other species, especially in winter. Another study revealed that the phenolic content of *Glechoma* as a cover plant, which has medicinal characteristics, too, varied across seasons (Varga, 2016).

The seasonal color changes of certain ornamental plants are another significant aspect of green spaces, creating a harmonious color palette and showcasing unique beauty (Wang, 2021). Thus, cover plants can also contribute to this color diversity in green spaces with their array of colors and seasonal changes. For example, the foliage of *Frankenia* transitions from green in spring and summer to orange and red from late autumn to late winter in non-tropical and semi-tropical regions.

The present study aimed to evaluate 18 cover plants in the climatic conditions of Gorgan, Iran, over the course of a year (four seasons).

MATERIALS AND METHODS

The research was conducted on the campus of the Faculty of Plant Production at Gorgan University of Agricultural Sciences and Natural Resources (36°48’33” N., 54°39’16” E.) over the course of one year. Eighteen plant species were acquired from a nursery in Pakdasht, Tehran. Table 1 lists their names and characteristics, and Fig. 1 provides their images. All plants were in pots with a diameter of 14 cm and a height of 12 cm. Five samples of each plant species were planted in circular pots with a diameter of 100 cm. The soil used for the research was standard agricultural soil, which was tested and analyzed by the Water and Soil Laboratory of Dr. Mahzari. The results are presented in table 2. All plants received uniform watering.

Table 1. The characteristics of the studied plant species.

Scientific name	Family	Ornamental parts	Water requirement	Propagation method
Crassula campfire	Crassulaceae	Leaf	Low	Seed/ Plant division
Frankenia thymifolia	Frankeniacea	Leaf	Low	Plant division/ Stem cutting
Hedera algeriensis	Araliaceae	Leaf	Moderate	Stem cutting/ Grafting
Ophiopogon japonicus	Asparagaceae	Leaf	Modrate	Plant division/ Seed
Festuca ovina	Poaceae	Leaf/ Flower	Low	Plant division/ Seed
Osteospermum ecklonis	Asteraceae	Flower/Leaf	Moderate	Plant division/ Seed
Liriope muscari	Asparagaceae	Leaf/ Flower	Low	Plant division/ Seed
Sedum reflexum	Crassulaceae	Leaf/ Flower	Low	Plant division/ Seed
Ajuga reptans	Lamiaceae	Leaf/ Flower	Moderate	Plant division/ Seed
Phalaris arundinacea	Poaceae	Leaf	Low	Plant division/ Seed
Ruellia tweediana	Acanthaceae	Leaf/ Flower	Low-Moderate	Plant division/ Seed/ Stem cutting
Plectranthus australis	Lamiaceae	Leaf	Moderate	Stem cutting
Carpobrotus acinaciformis	Aizoaceae	Leaf/ Flower	Low	Seed/ Stem cutting
Alternanthera bettzickiana	Amaranthaceae	Leaf	High	Seed/ Stem cutting
Armeria maritima	Plumbaginaceae	Leaf/ Flower	Low	Plant division/ Seed
Lysimachia nummularia	Primulaceae	Leaf	High	Plant division/ Seed
Glechoma hederacea	Lamiaceae	Leaf	Low	Seed/ Stem cutting
Cerastium tomentosum	Caryophyllaceae	Leaf/ Flower	Moderate	Plant division/ Seed/ Stem cutting

Table 2. Physical and chemical characteristics of soilused.

Lab.No	Description	Dept. (cm)	pH	EC	Saturation percentage (%)	Total nitrogen (%)	N (%)	Organic carbon (%)	P (ppm)	K (ppm)	Clay (%)	Silt (%)	Sand (%)	Texture
757	Gorgan	0-30	7.34	1.52	15.3	9.18	0.38	1.8	7.6	296	18	66	16	Si – L

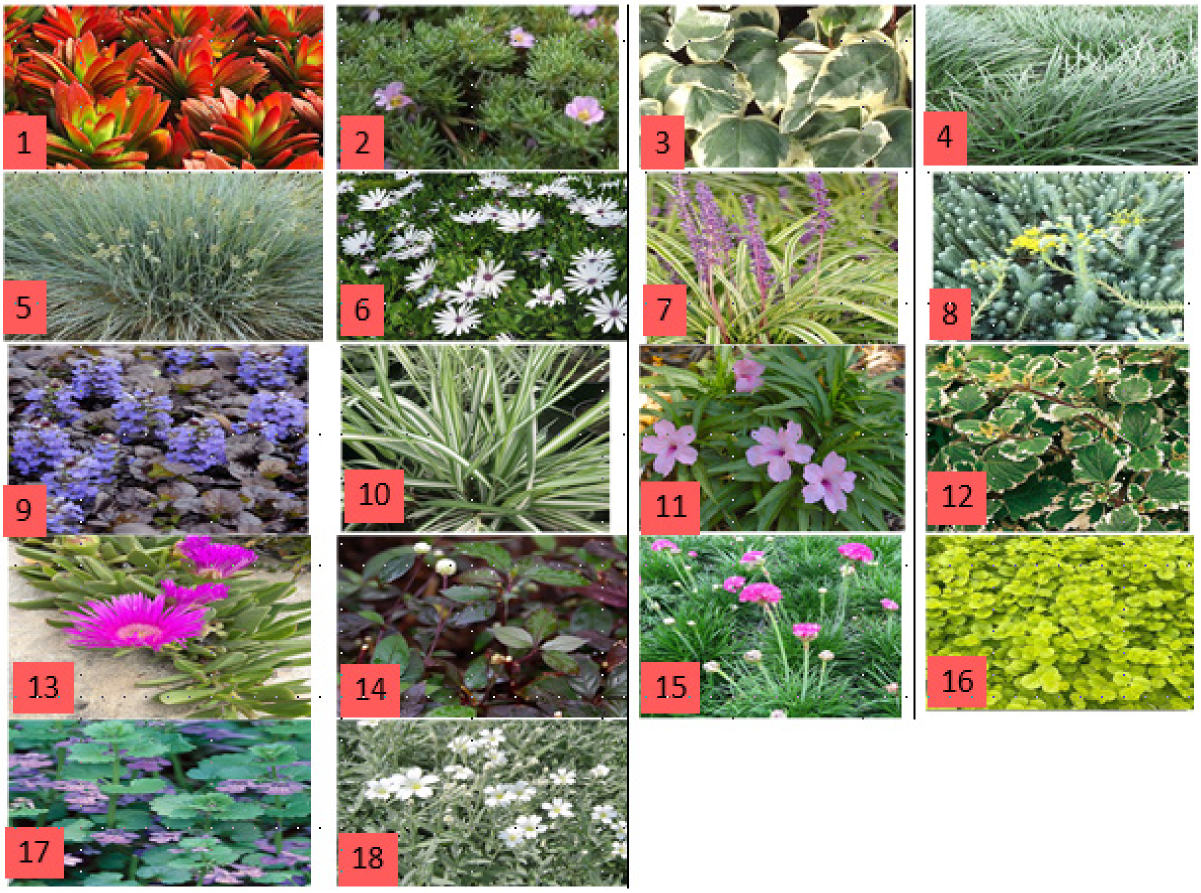

Fig. 1. *Crassula campfire*; 2. *Frankenia thymifolia*; 3. *Hedera algeriensis*; 4. *Ophiopogon japonicus*; 5. *Festuca ovina*; 6. *Osteospermum ecklonis*; 7. *Liriope muscari*; 8. *Sedum reflexum*; 9. *Ajuga reptans*; 10. *Phalaris arundinacea*; 11. *Ruellia tweediana*; 12. *Plectranthus australis*; 13. *Carpobrotus acinaciformis*; 14. *Alternanthera bettzickiana*; 15. *Armeria maritima*; 16. *Lysimachia nummularia*; 17. *Glechoma hederacea*; 18. *Cerastium tomentosum*.

The traits measured included appearance quality, chlorophyll a, b, and total, carotenoid content, and plant growth percentage. The appearance quality was determined through scoring parameters like leaf freshness and the presence or absence of spots on the leaves, which were evaluated by several graduate students (Zarei *et al*., 2018).

Chlorophyll content was measured following Barnes *et al*.'s (1992) method. So, 1 g of fresh leaves from each replication was precisely weighed and then chopped into small pieces using a sharp instrument like a scalpel. The minced samples were placed in a test tube and mixed with 10 ml of dimethyl sulfoxide (DMSO). They were then oven-dried at 75-80°C for 3 hours. Afterward, 1 ml of this mixture was transferred to a new test tube and diluted to 5 ml with DMSO. Pure DMSO served as the control. The absorbance of the samples was measured using a Unic-2800 spectrophotometer (Unico, the US) at 645, 663, and 480 nm to determine the chlorophyll a, b, and total chlorophyll contents. The readings were put in Eq. (1):

$$\begin{aligned} &\text{Chl. a (mg/g F.W.)} = 12.7(A663) - 2.69(A645)\times V/1000\times W \\ &\text{Chl. b (mg/g F.W.)} = 22.9(A645) - 4.68(A663)\times V/1000\times W \qquad (1) \\ &\text{Chl. total (mg/g F.w)} = 20.2(A645) + 8.02(A663)\times V/1000\times W \end{aligned}$$

in which V represents the volume of the filtered solution (the supernatant), and W represents the sample fresh weight in g.

Arnon's (1965) method was employed to quantify the carotenoid content in gerbera. Initially, 0.5 g of petals were ground with 10 ml of 80% acetone in a porcelain mortar. The resulting mixture was transferred to plastic centrifuge tubes and spun at 5000 rpm and 20 °C using a HERMLE-Z300 centrifuge for 5 minutes. The clear supernatant was decanted, and the process was repeated with acetone. This procedure was performed three times until the residual plant tissue became colorless. The final solution was then adjusted to a volume of 50 ml with 80% acetone and was poured into a spectrophotometer cuvette to read its absorbance at 480 and 510 nm. Also, 80% acetone was used as the control. The carotenoid content was calculated in mg of carotenoids per g of fresh flower tissue using Eq. (2).

$$\text{Carotenoid content (mg/g F.W.)} = [7.6\,(A480) - 1.49\,(A510)] \times V/W \quad (2)$$

Imager software was utilized to calculate the plant growth and coverage percentage. This software is capable of differentiating the plant from the soil in overhead photographs and subsequently estimating the area shaded by the plant foliage. While this method does not directly measure the leaf area index, it can measure horizontal growth changes in plants by comparing the shaded area produced at different time intervals, which is particularly useful for evaluating the growth of cover plants. The software can also be used to measure leaf area or to distinguish leaf area from pest-affected areas for assessing damage or decay. The software is typically calibrated using a reference paper sheet with known dimensions placed in the initial photographs (Fig. 2).

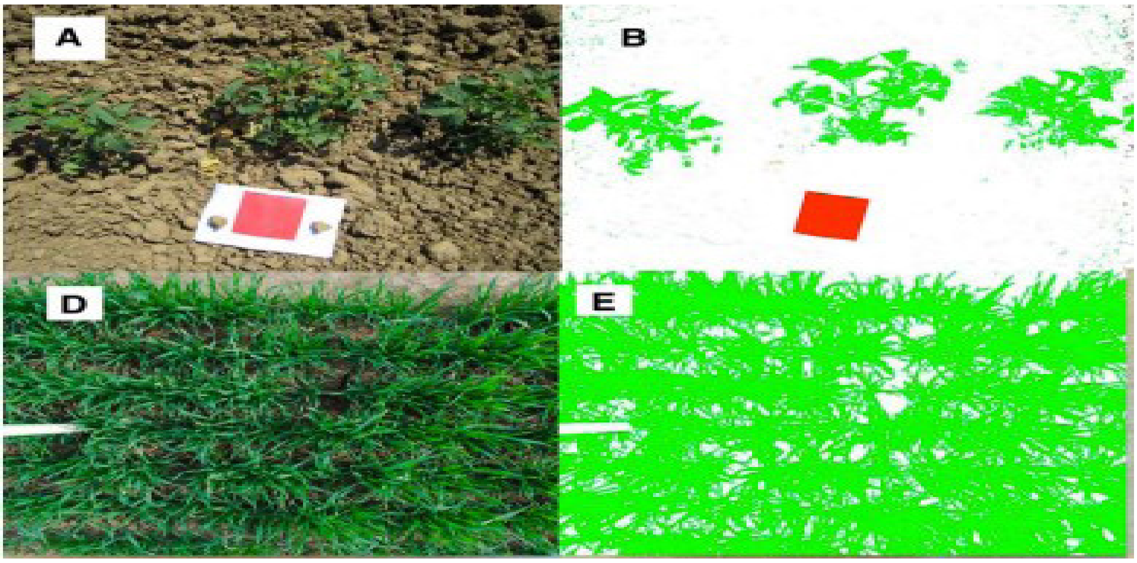

Fig. 2. The shade on the soil surface created by the plant as distinguished by the imager software on the soil surface.

Data were analyzed using SAS software, and the means were compared using the LSD test.

RESULTS AND DISCUSSION

Based on the results of analysis of variance (ANOVA), the plant type significantly ($P < 0.01$) affects chlorophyll a, b, total, and carotenoid levels. However, the effect of time (four seasons) and its interaction with cover plant type were not significant on these traits. Additionally, the effect of plant type, time, and their interaction was found to be significant ($P < 0.01$) on visual quality (Table 3).

Table 3. The analysis of variance for the effect of cover plant species and time on the measured traits.

S.o.V	df	Chlorophyll a	Chlorophyll b	Total chlorophyll	Carotenoid	Growth rate
Species	19	1.849**	0.494**	3.842**	0.349**	6823.847**
Time	3	11.612ns	1.444ns	21.250ns	5.003ns	8350.5643ns
Species × time	57	10.260ns	0.150ns	1.007ns	0.198ns	1334.310ns
Error	160	0.010	0.012	0.023	0.011	0.7591
CV (%)		8.852	28.552	9.969	13.746	1.597

*, ** and ns: Significant at P < 0.05, P < 0.01 and insignificant based on the LSD test, respectively.

Growth rate

The comparison of data means indicated that the highest and lowest growth rates throughout the four seasons were observed in *Carpobrotus acinaciformis* and *Festuca ovina*, respectively (Table 4).

Table 4. The comparison of means for the measured traits of the studied cover plants.

Species	Growth rate	Chlorophyll a	Chlorophyll b	Total chlorophyll	Carotenoid
Crassula campfire	67.81e	0.695m	0.182 f-i	0.877ij	0.642hij
Frankenia thymifolia	82.167c	1.502d	0.606c	2.109c	1.230b
Hedera algeriensis	36.336k	1.089fg	0.239ef	1.328ef	0.704ghi
Ophiopogon japonicus	46.61hi	0.882ijk	0.192e-h	1.074gh	0.700ghi
Festuca ovina	33.81l	0.828kl	0.546c	1.375ef	0.797fg
Osteospermum ecklonis	81.234c	1.001gh	0.572c	1.573d	0.917ef
Liriope muscari	54.157f	0.638mn	0.095hi	0.734jk	0.611j
Sedum reflexum	88.096b	1.161f	0.313dec	1.475de	0.718ghi
Ajuga reptans	34.299l	1.715c	0.546c	2.262c	1.044cd
Phalaris arundinacea	52.835fg	0.969hij	0.396d	1.366ef	0.595ij
Ruellia tweediana	47.277h	0.873jk	0.541c	1.415de	1.115bc
Plectranthus australis	48.363h	0.997ghi	0.231efg	1.228fg	0.714ghi
Carpobrotus acinaciformis	96.925 a	2.756a	1.165a	3.922a	0.662hi
Alternanthera bettzickiana	88.048b	1.345e	0.225efg	1.570d	1.383a
Armeria maritima	38.506j	1.367e	0.909b	2.276c	0.989de
Lysimachia nummularia	73.766d	0.719lm	0.189e-i	0.909hij	0.600ij
Glechoma hederacea	89.343b	0.838k	0.191e-i	1.030hi	0.642hij
Cerastium tomentosum	68.439e	2.155b	0.559c	2.714b	0.746gh

*In each column, means with similar letter(s) are not significantly different (P < 0.05) using the LSD test.

The vegetative growth of cover plants is a critical factor influencing their selection. The ability to cover the ground and the resultant aesthetic appeal are greatly dependent on the rate of the plant's vegetative growth. Cover plants exhibit a range of growth rates, from slow to fast. This parameter is affected by various factors, including climatic conditions (Zarei *et al*., 2018). The plants explored in this study also varied in their growth rates. Among the plants with a running growth habit, *Alternanthera bettzickiana, Glechoma hederacea,* and *Sedum reflexum* had the highest growth rate after *Carpobrotus acinaciformis*, but *Hedera algeriensis* had a lower growth rate over one year than the others although it is a runner plant. Typically, this plant thrives in bushes, hedges, and shaded areas (Reichard, 2000). Consequently, one reason for the observed growth rate could be the full sunlight exposure in the test environment, as these plants were cultivated in an unshaded area free of any obstacles that could reduce light availability. A study conducted in Italy under Mediterranean conditions examined four ornamental cover plants. The findings showed that *Hedera algeriensis* covered approximately 85% of the target area over four seasons (Ruggeri *et al*., 2016), which contrasts with our results. On the other hand, among plants with a bushy to upright growth habit, *Osteospermum ecklonis* exhibited the highest growth rate, while the lowest was observed in *Festuca ovina*. However, fescue was found to effectively control weeds in the spaces between apple trees in another study (Hartley *et al*., 2000).

Foo *et al*. (2011) conducted a study on 12 cover plants, including *Ophiopogon japonicus*, which demonstrated moderate growth and coverage of about 50%, aligning with our findings.

Chlorophyll and carotenoid contents

Table 4 indicates that *Carpobrotus acinaciformis* exhibited the highest levels of chlorophyll a, b, and total, while the lowest levels were observed in *Liriope muscari*, with no significant difference from *Crassula campfire* and *Lysimachia nummularia*. Plants synthesize over 2000 compounds, many of which are colorful and known as pigments (Tanaka *et al.*, 2008). Pigments are categorized into four major groups in higher plants: Chlorophylls, carotenoids, anthocyanins, and betalains (Gandia-Hererro *et al.*, 2013). Greenness serves as a quality indicator in plants, although cover plants exhibit color variations beyond those induced by seasonal changes. Plants with leaves that are pied (have two colors) or typically less green contain lower chlorophyll contents. In our study, the plants that had their almost fully green foliage with no color change in cold conditions included *Ophiopogon japonicus, Osteospermum ecklonis, Ruellia tweediana, Carpobrotus acinaciformis, Armeria maritima*, and *Glechoma hederacea*, whereas the other 12 species displayed a diverse color spectrum. Although, the leaf color of *Frankenia thymifolia* and *Alternanthera bettzickiana* shifted to orange and red from late autumn to late winter, respectively, their chlorophyll contents did not show significant variations over time. A study evaluated 10 cover plants in the Kish Island region. The findings revealed that *Frankenia thymifolia* and *Carpobrotus acinaciformis* had the highest chlorophyll content (Shoshtarian *et al*., 2011), corroborating our results. On the other hand, the reduced chlorophyll detected in *Crassula campfire* in the present study may be attributed to the dominance of pink-to-red pigments in its succulent leaves over the green color in its typical growth conditions throughout the year, resulting in diminished levels of chlorophyll.

As per table 4, *Alternanthera bettzickiana* showed the highest carotenoid content in its leaves, closely followed by *Frankenia thymifolia.* On the other hand, *Phalaris arundinacea* had the lowest carotenoid content. The cold-induced color changes in *Alternanthera bettzickiana* and *Frankenia thymifolia* influenced the average carotenoid levels in their leaves compared to other cover plants studied. Jozay *et al.* (2023) noted that the carotenoid content in *Frankenia* *thymifolia* increased as it got cold in winter in Mashhad, Iran, as opposed to spring and summer. The lower carotenoid content in *Phalaris arundinacea* could be linked to the pied color of its foliage. Pied leaves are distinguished by white, yellow, or red sections, which vary based on the presence or absence of chlorophylls, carotenoids, and anthocyanins (Esteban *et al*., 2008).

Visual quality

Based on the comparison of data means, the best visual quality was for *Osteospermum ecklonis* in spring, followed by *Frankenia thymifolia*, *Plectranthus australis*, and *Lysimachia nummularia*. Also, the lowest visual quality in spring was observed in *Crassula campfire, Ophiopogon japonicus, Ajuga reptans, Ruellia tweediana, Armeria maritima,* and *Cerastium tomentosum*. During the summer, *Carpobrotus acinaciformis* and *Glechoma hederacea* had the highest and lowest visual quality, respectively. The highest and lowest visual quality in the autumn was related to *Liriope muscari* and *Ajuga reptans*, respectively. *Osteospermum ecklonis* had the best, and *Plectranthus australis* had the worst visual quality in the winter (Table 5).

Table 5. The visual quality of the cover plants in four seasons on a scale of 0-10.

Species	Winter	Autumn	Summer	Spring
Crassula campfire	2^{g}	7^{c}	6^{d}	6^{d}
Frankenia thymifolia	8^{b}	8^{b}	7^{c}	8^{b}
Hedera algeriensis	4^{f}	7^{c}	5^{e}	7^{c}
Ophiopogon japonicus	6^{d}	6^{d}	5^{e}	6^{d}
Festuca ovina	6^{d}	6^{d}	5^{e}	7^{c}
Osteospermum ecklonis	9^{a}	8^{b}	7^{c}	9^{a}
Liriope muscari	5^{e}	9^{a}	6^{d}	7^{c}
Sedum reflexum	6^{d}	8^{b}	6^{d}	7^{c}
Ajuga reptans	6^{d}	5^{e}	5^{e}	6^{d}
Phalaris arundinacea	7^{c}	6^{d}	5^{e}	7^{c}
Ruellia tweediana	8^{b}	7^{c}	7^{c}	6^{d}
Plectranthus australis	1^{h}	7^{c}	8^{b}	8^{b}
Carpobrotus acinaciformis	7^{c}	8^{b}	9^{a}	7^{c}
Alternanthera bettzickiana	1^{h}	7^{c}	8^{b}	7^{c}
Armeria maritima	7^{c}	8^{b}	8^{b}	6^{d}
Lysimachia nummularia	2^{g}	7^{c}	4^{f}	8^{b}
Glechoma hederacea	2^{g}	6^{d}	3^{g}	8^{b}
Cerastium tomentosum	4^{f}	7^{c}	4^{f}	6^{d}

Visual quality, which is influenced by environmental factors such as light, temperature, and humidity, is a crucial criterion in green spaces. Plants have varying requirements. If their specific environmental needs are met, they will exhibit high quality; otherwise, their appearance quality will diminish. The high visual of *Osteospermum ecklonis* in spring, autumn, and winter can be attributed to its cooler temperature requirements, and as is observed in Fig. 2, Gorgan had relatively cooler temperatures in these three seasons. Since *Carpobrotus acinaciformis* is a tropical species (Campoy *et al*., 2021), it achieved the highest appearance quality in summer. It, however, scored relatively well in other seasons, indicating its tolerance to various temperature ranges. According to Campoy *et al*. (2021), *Carpobrotus acinaciformis* is very highly tolerant of climatic fluctuations. The low appearance quality of *Glechoma hederacea* in summer was due to leaf yellowing caused by intense light exposure, which resulted in leaf burn. However, its regrowth in autumn was facilitated by the expansion of its stolons in spring. *Liriope muscari* stood out for its excellent appearance and freshness in autumn, enhanced by the bloom of its lilac flowers. The superior visual quality of this plant in autumn, as opposed to spring and summer, may be linked to lower light intensity during this season. *Liriope muscari* thrives best in semi-shade conditions, achieving optimal quality (Gilman, 1999). Zhang *et al*. (2020) observed that *Liriope muscari*'s best growth occurred under low light conditions and tree shade.

CONCLUSIONS

The research revealed that, out of the 18 cover crops examined, the most suitable species for the urban green spaces of Gorgan under full sunlight and with no shading are *Frankenia thymifolia, Osteospermum ecklonis, Liriope muscari, Sedum reflexum, Ruellia tweediana, Carpobrotus acinaciformis,* and *Armeria maritima*. Additionally, plants like C*erastium tomentosum, Phalaris arundinacea,* and *Lysimachia nummularia*, which exhibited yellowing and diminished growth and appearance quality due to the intense summer light in the summer, are likely to thrive in Gorgan's urban green spaces if they are cultivated in shaded areas.

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