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Seasonal Variations in the Soil Seed Bank of the Wadi (Valley) Al-Sahel Al-Gharbi (Al-Butnan Plateau - Marmarica) Northeast Libya

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التغيرات الموسمية في خزان بذور التربة بوادي السهل الغربي (هضبة البطنان – مارماريكا) شمال شرق ليبيا

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Abstract:

This study examined the seed bank in the (Valley) Al-Sahel Al-Gharbi area, located on the Al-Butnan plateau in northeastern Libya. Conducted between 2021 and 2022, the area was divided into six main sites based on elevation and vegetation cover distribution. From these sites, four individual soil samples were taken from each location, totaling 96 samples throughout the four seasons. The study aimed to investigate the seasonal differences in seed density and viability, as well as to identify the average number of seeds of legume species in the area. The total number of seeds was 19,150 seeds/m2, while the average seed density was approximately 797.91 seeds/m2, and seed viability was 72.49%. The highest average seed density was recorded in autumn with 1,083.3 seeds/m2, and the lowest in spring with 533.33 seeds/m2. The highest seed viability rate was observed in autumn at 83.07%, and the lowest in spring at 59.53%. There were significant differences in seed density ($p < 0.04$) and very significant differences in seed viability ($p < 0.000001$). The highest average of Fabaceae seeds was in winter with 83.33 seeds/m2, and the lowest in spring with 6.25 seeds/m2., It was observed that the area has a high seed bank and an increase in seed density, possibly due to the dominance of annual species because of the climate and the intensity of human activities in the area.

Keywords: Seasonal Differences, Soil Seed Bank, Seed Density, Seed Viability, Fabaceae Seeds.

الملخص
تتناول هذه الدراسة خزان البذور في منطقة وادي السهل الغربي الواقعة على هضبة البطنان في شمال شرق ليبيا أُجريت الدراسة خلال عامي 2021–2022، حيث قُسمت المنطقة إلى ستة مواقع رئيسية اعتمادًا على الارتفاع وتوزيع الغطاء النباتي، ومن كل موقع تم أخذ أربع عينات تربة فردية، ليبلغ مجموع العينات 96 عينة خلال الفصول الأربعة. هدفت الدراسة إلى تقييم الفروق الموسمية في كثافة البذور وحيويتها، وكذلك تحديد المتوسط العام لعدد بذور الفصيلة البقولية في المنطقة. بلغ العدد الكلي للبذور 19,150 بذرة/م²، بينما بلغ متوسط كثافة البذور حوالي 797.91 بذرة/م²، وبلغت نسبة الحيوية 72.49%. سُجلت أعلى كثافة للبذور في فصل الخريف بمتوسط 1,083.3 بذرة/م²، وأدناها في الربيع بمتوسط 533.33 بذرة/م²، كما ظهرت أعلى نسبة لحيوية البذور في الخريف (83.07%)، وأدناها في الربيع (59.53%)، وكشفت الدراسة عن فروق معنوية في كثافة البذور (p < 0.04) وفروق عالية المعنوية في الحيوية .(p < 0.000001) أما أعلى متوسط لبذور الفصيلة البقولية (Fabaceae) فقد سُجل في الشتاء بمتوسط 83.33 بذرة/م²، وأدناه في الربيع بمتوسط 6.25 بذرة/م². وأظهرت النتائج أن المنطقة تحتوي على بنك بذور مرتفع وكثافة كبيرة للبذور، مما قد يُعزى إلى سيادة الأنواع الحولية نتيجة الظروف المناخية وشدة الأنشطة البشرية في المنطقة.

الكلمات المفتاحية: الفروق الموسمية، خزان بذور التربة، كثافة البذور، حيوية البذور، بذور الفصيلة البقولية.

Introduction:

Within terrestrial ecosystems, the soil seed bank represents one of the most essential mechanisms ensuring the long-term continuity of vegetation. It encompasses the collection of viable propagules that remain embedded in the soil profile or organic surface layers, maintaining the potential to regenerate plant cover after it has been lost through environmental stress, grazing, or anthropogenic disturbance. This biological repository acts as a living archive, enabling plant communities to recover even after extended periods of unfavorable climatic conditions [1].

Ecologically, seed banks are generally separated into two main functional categories. The transient seed bank includes seeds whose viability is restricted to a single seasonal cycle, while the persistent seed bank retains seeds that remain capable of germination for multiple years, thereby allowing vegetation to endure recurrent disturbance or drought [2]; [3]; [4]; [5].The operational distinction between these two categories, as highlighted by Walek et al. [6], is approximately one calendar year.

Despite their crucial role in maintaining biodiversity and ecosystem resilience, empirical data from desert and semi-arid regions remain limited. In such environments, seeds are often minute, lacking morphological adaptations for dispersal, and exhibit considerable temporal and spatial variability in density. Multiple studies demonstrate that the composition and abundance of seed banks are closely linked to soil properties, particularly texture, moisture availability, and nutrient content [7].

In the context of arid landscapes, the seed bank acts as a buffering mechanism, ensuring vegetation persistence by supplying a continuous source of viable seeds capable of germination when conditions become favorable [8].Analyzing the structure and dynamics of the seed bank therefore provides insight into both the current ecological status and historical trajectories of ecosystems, assisting in the evaluation of environmental degradation and human impacts [9].

Across Libya, where desert terrain predominates, desertification poses a serious ecological threat. According to FAO [10], desert encroachment has reached alarming levels in some localities, advancing by up to 200 m annually. Research in northeastern Libya has explored how temperature and humidity gradients influence seed density and diversity within the soil [11]. Understanding these dynamics is fundamental for evaluating how land-use pressure and climatic stress alter vegetation recovery potential and species persistence.

The present investigation, conducted in the Sahl Al-Gharbi Valley, seeks to quantify seasonal variations in seed density and germination potential, emphasizing leguminous taxa owing to their contribution to soil fertility and nitrogen fixation. The study aims to elucidate relationships among environmental characteristics, seed longevity, and vegetation restoration capacity, offering a scientific basis for biodiversity conservation and rehabilitation strategies in semi-desert ecosystems of northeastern Libya. Foundational work [12]; [13]; [14]; [11]; [15]; [16]; and [17] has contributed valuable baseline knowledge, upon which the current research further develops a comprehensive ecological perspective on seed-bank function in degraded arid regions.

Study area:

The study area is geographically located west of the city of Tobruk in the Al-Butnan plateau (Marmarica) in northeastern Libya. The valley extends from south to north, emptying its watershed into the Mediterranean Sea. It is bordered to the south by the Ras Mdawar area, to the west by Wadi Al-Karath, Wadi Bouhtisha, and Wadi Shabraq at Sidi Musa, and to the east by Wadi Al-Maghrin and Wadi Bougamal. According to this delineation, the study area is located between the longitudes 23°23’0”E to 23°23’30”E and latitudes 32°1’30”N to 32°10’30”N. The area covers approximately 54.75 km², with a length of 17.67 km and a width of 9.12 km. The highest point is approximately 209 meters above sea level, and the lowest point is less than 1 meter, as shown in Figure 1.

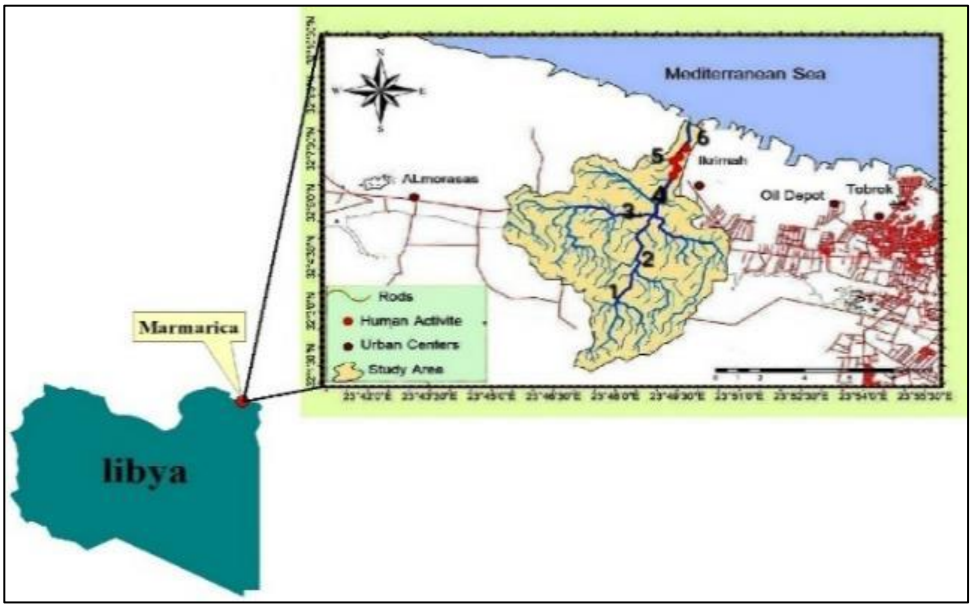

Figure (1): Boundaries of the study area

Climate and soils are the primary factors determining the type of natural vegetation in the area. The soils in the study area are classified as alkaline, ranging from salty to highly saline, relatively poor in organic matter, and of low fertility. This is attributed to the arid conditions and their chemical composition. The prevailing soil color varies between brown and yellow. The study area falls within the Haplic Calsiols category, characterized by the accumulation of calcium carbonates [18], Consequently, the vegetation cover is limited and sparse also due to the arid and semi-desert climate, approximately 176.2 mm. As documented by [11], the mean annual maximum temperature reaches nearly 24 °C, whereas the mean annual minimum is about 16 °C. The average relative humidity throughout the year is around 71 %, reflecting the region’s proximity to maritime air masses and its transitional climatic setting.

One of the most influential climatic features is the southerly wind system, locally referred to as the Ghibli, a hot, desiccating, and turbulent air stream that originates from the interior desert. According to [19], the Ghibli often causes substantial physiological stress to vegetation and serious mechanical damage to crops. Under these conditions, the limited moisture regime supports only xerophytic steppe vegetation, dominated by low-growing perennial shrubs and evergreen species that exhibit strong adaptations to water scarcity and temperature extremes typical of the semi-arid environment., This sparse growth includes plants like *Thymelaea hirsuta* (L.) Endl, *Haloxylon scoparium* Pomel, *Artemisia herba-alba* Asso, *Retama raetam* (Forssk.) Webb & Berthel., and Deverra tortuosa (Desf.) DC. annual plants dominate this area, forming the bulk of the vegetation. These include various grasses and herbs that emerge with the rainy season and disappear during droughts, leading to an increase in vegetation cover in spring after rainfall. The annuals disappear by the start of summer, leaving behind seeds awaiting the next rainy season to restart their life cycle. Seed density in the soil is expected to be highest in autumn, as plants would have flowered, completed their life cycle, and produced seeds [20], The area suffers from a accumulation of human activities, leading to signs of degradation, poor resource management, overgrazing, rainfed and irrigated agriculture, logging road, construction quarrying, and the collection of medicinal and economic plants. The construction of check dams, which are crucial for rainwater harvesting.

Material and methods:

1.Soil Seed Bank Density and Viability:

Visits to the area were conducted throughout the year to collect soil samples every season, four individual soil samples were taken from each site. The region was divided into 6 sites, from the top of the valley to the coastal area, covering an area of 500 m². Geographic coordinates and elevations above sea level for the studied sites were recorded using a Global Positioning System (GPS) device (Table1).

Table (1): Geographic coordinates and elevation of soil samples. Number of samples (composed of 4 subsamples) in each habitat type.

Location	Longitude (E°)	Latitude (N°)	Elevation (M)	Number of samples at the bottom of valley
Beginning of the mountain valley	23°49'15.64644"	32°6'30.10680"	65	4
Middle of the mountain valley	23°49'18.35184"	32°6'40.10364"	45	4
Interior of the valley	23°49'26.29524"	32°7'6.89736"	25	4
Foot of the valley	23°49'30.65916"	32°7'29.69508"	35	4
Agricultural area	23°49'40.86624"	32°7'40.66716"	18	4
Coastal area	23°49'49.92024"	32°7'53.90364"	4	4

Soil samples were collected at a depth of 10 cm, examining a square meter for each composite soil sample by randomly taking a quarter meter square (25×25 cm) area with four replicates to ensure the sample was as representative as possible of the site from which it was taken. The soil was scraped over a specific area and depth, where every four individual soil samples were mixed to form a single composite sample. These were then placed in sealed plastic bags, labeled to represent the site of collection, and immediately transported to the laboratory for seed separation. Initially, the samples were air-dried for 72 hours and then sieved through a 2 mm mesh to remove stones, gravel, and any large-sized seeds. Seeds were separated using a flotation method in a chemical suspension (Flotation in a Salt Solution) following the method of [21] and modified by [22].

A chemical solution was prepared by dissolving 20 g of Sodium Hexameta phosphate and 10 g of Sodium Bicarbonate in one liter of water, and 500 g of Potassium Carbonate in one liter of water. The first two compounds ensured the disintegration of soil granules, and the third compound caused all organic materials to float to the surface of the solution. Two hundred grams of soil were placed in a container with one liter of the previously prepared solution and stirred with a steel spoon for 30 seconds. The mixture was left for one hour to allow all organic materials to float, after which the organic materials were skimmed off and rinsed with plain water to remove any soil granules or chemical residues. The materials were then left to dry on a 15 cm diameter filter paper for 24 hours. To ensure greater accuracy of results, three replicates were conducted for each sample and their arithmetic mean was calculated. After drying, seeds were sorted from the rest of the organic material under a binocular stereomicroscope using forceps. Seed viability was measured by lightly pressing the seed under the microscope with the forceps; if the seed resisted the light pressure and its external shape was intact, it was considered viable [23]; [24]; [25] From this the percentage of seed viability was calculated, and the number of seeds/m² was recalculated using the equation as reported by [16].

Number of seeds in 200g of soil × 1.2× 10^5
Seed/m² =200

1.2 = Average bulk density of the soil in the study area (soil bulk density).
10^5 = Volume of one square meter of soil surface at a depth of 10 cm from which the sample was taken, measured in cubic centimeters.

2. Statistical analyses used:

The statistical analyses used involved processing the collected data, categorizing, and tabulating it in tables, and statistically analyzing it using IBM Spss Statistics Version 22. The statistical analyses included descriptive analysis, testing of data distribution, analysis of variance, and presentation of statistical data in the form of tables and graphs.

Results and discussion:

Table (2): Total average seed density and vitality for all seasons of the year

N		winter		Spring		Summer		Autumn	
	Location	Seed density	Seed vitality %	Seed density	Seed vitality %	Seed density	Seed vitality %	Seed density	Seed vitality %
1	Beginning of the mountain valley	800	75.20	450	55.32	700	71.42	1100	80.77
2	Middle of the mountain valley	1000	80.33	600	65.12	850	78.35	1200	90.23

3	**Interior of the valley**	700	72.52	300	60.65	500	65.20	900	78.65
4	**Foot of the valley**	1300	80.38	900	75.14	1000	78.54	1500	92.64
5	**Agricultural area**	900	78.63	700	60.32	600	68.39	1000	85.66
6	**Coastal area**	600	75.22	250	40.68	500	60.10	800	70.49
*	**Total**	5300	462.28	3200	357.23	4150	422	6500	498.44

Table (3): Seed bank density (seed/m²) and seed viability percentage (%)

Indicator	Maximum value	Lowest value	Mean	Std.Deviation
Seed density (b/m²)	1500	250	797.91	305.55
Seed vitality %	92.64	40.68	72.49	11.67

The total number of seeds in the SSB collected amounted to about 19,150 seeds/m². The highest value of seed density in a sample ranged from 1,500 seeds/m² to the lowest value of 250 seeds/m², with an average of 797.91 (Table 3, Figure 2). Seed density varied between locations in the area, with the fourth and fifth sites (Agricultural area and costal area) recording the highest seed density. This increase in the density of the SSB could be attributed to the establishment of dykes at these sites, as well as to increased human activities such as transportation, grazing, plowing, and the spread of irrigated farms. These results align with the findings of [26], [14], and [16], the proportion of small seeds was higher than that of large seeds, which could also be due to trampling and grazing or the effect of wind. These results are consistent with those mentioned by [27]

Seed germination occurs during specific periods of the year that coincide with environmental conditions favorable for plant establishment and reproductive success. When such conditions are unfavorable, seeds enter a state of dormancy, a physiological adaptation that prevents premature germination and enhances survival until external factors become optimal.

In temperate environments, the majority of seeds germinate during spring or autumn, when temperature and moisture levels are suitable for seedling development. However, when germination does not take place within these optimal windows, seeds may enter a secondary dormancy phase, remaining inactive until a subsequent season provides more favorable conditions.

For instance, seeds that mature in autumn typically remain dormant throughout winter, resuming germination as temperatures rise in spring. Conversely, seeds dispersed in spring may become dormant during summer, reactivating their germination potential in autumn.

The duration of dormancy varies widely among species. Some seeds retain viability for a year or longer, germinating only when precise environmental cues are met, while others germinate within a single growing season and lose their viability shortly thereafter.

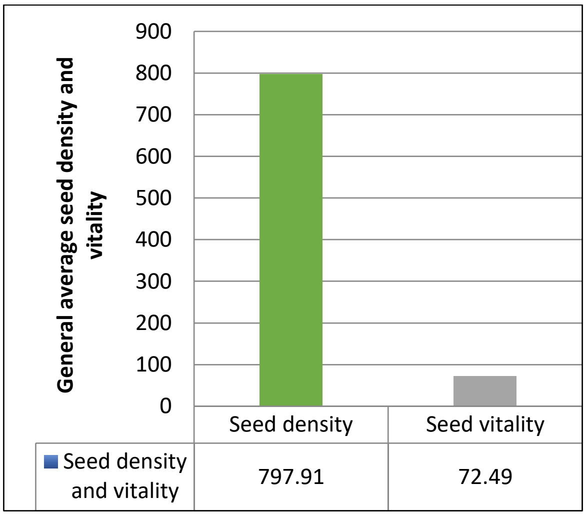

Figure (2): Seed bank density (seed/m2) and vitality ratio.

Seasonal Variations in Seed Density:

As shown in Table 4, the highest arithmetic mean for seed density among the seasons was recorded in autumn, with a value of 1,083.3 seeds/m². The lowest arithmetic mean was observed in spring, with a value of 533.33 seeds/m² (Figure 3).

Table (4): Difference in average seed density

Indicator	Seasons								P.Value
	Winter		spring		summer		autumn		
Number of seeds (seeds/m²)	Mean	Std.Deviation	Mean	Std.Deviation	Mean	Std.Deviation	Mean	Std.Deviation	0.004
	883.3	248.3	533.3	248.3	691.6	201	1083.3	248.3	

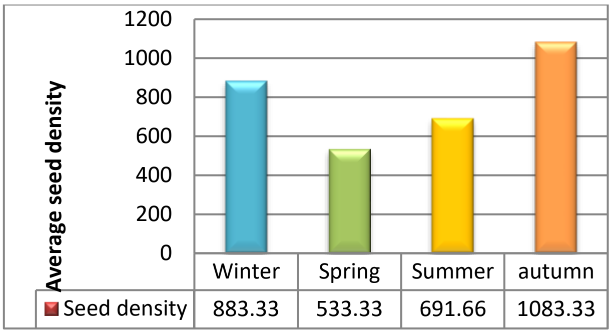

Figure (3): Difference in average seed density

The seasonal differences in seed vitality are illustrated in (Table 5), showing that the highest average seed vitality was recorded in autumn with an arithmetic mean of 83.07%, while the lowest average was observed in spring with an arithmetic mean of 59.53% (Figure 4).

Table (5): Difference in seed vitality

Indicator	Seasons								P.Value
	Winter		Spring		Summer		Autumn		
Seed vitality (%)	Mean	Std.Deviation	Mean	Std.Deviation	Mean	Std.Deviation	Mean	Std.Deviation	0.000
	77.04	3.21	59.53	11.40	70.33	7.31	83.07	8.15	

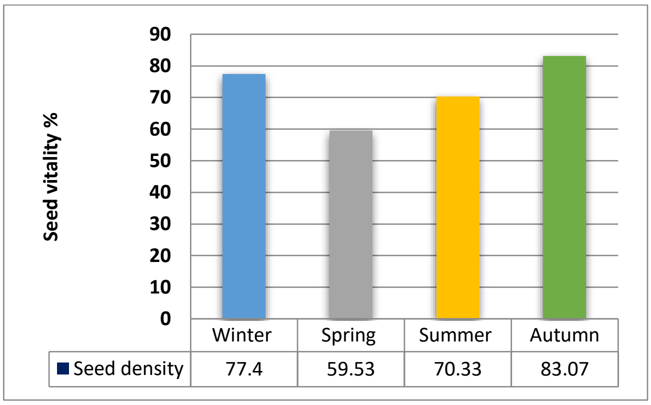

Figure (4): The difference in seed vitality

These results indicate that the SSB density and vitality of the area are relatively high, likely due to most of the collected species being annual seeds. Moreover, wadiis are areas where the necessary conditions of surface runoff, terrain, and soil. These factors have led to vegetation cover especially the annual portion, and consequently, the number of seeds in the soil. It is known that seeds proliferate in low-lying and protected areas, like the bottoms of wadiis. The highest average density and vitality of seeds were observed in autumn, with the lowest average in spring. This is because seeds in autumn achieve higher values due to addition and storage processes during the summer, and germination occurs after receiving a suitable amount of water. This leads to a germination process for these seeds, where their quantity in spring decreases from what it was in autumn. These results are consistent with those mentioned by [12], [17], who confirmed that most seeds in spring are in the germination phase, especially annuals. The statistical analysis results also show significant differences between the seasons in seed density, with a significant difference between spring and autumn and between summer and autumn in favor of autumn ($F=6035$; p-value 0.04). Additionally, there are very significant differences in seed vitality between the seasons, with a significant difference between winter and spring in favor of winter, and between spring and autumn in favor of autumn with a very significant difference ($F=9.377$; p-value<0.001).

Average Seasonal Density of Fabaceae Seeds (Fabaceae Seed Total):

Where the total number of Fabaceae seeds was 4150 seeds/m². The highest average was in autumn with a value of 83.33 seeds/m², followed by winter with an average of 58.33 seeds/m², then summer with an average of 25 seeds/m², and the lowest value was in spring with an average of 6.25 seeds/m² (Figure 5).

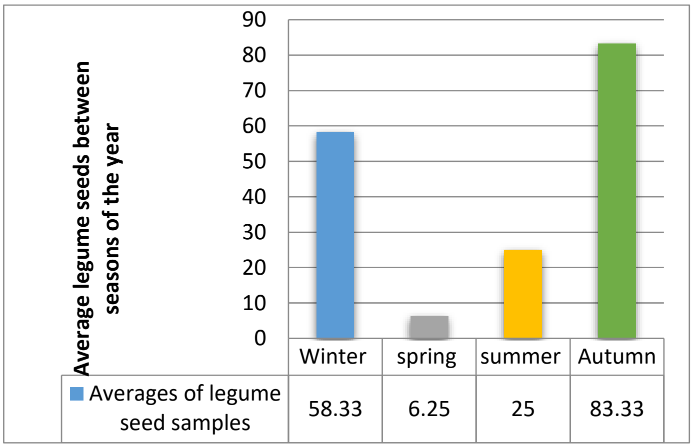

Figure (5): Average seed density of Fabaceae between seasons of the year.

From these results, it becomes clear that the number of Fabaceae seeds in the study area is approximately 4,500 seeds/m², constituting about 23.49% of the total seed count, that is about quarter of the SSB of the study area making them the most prevalent seeds. This prevalence is due to their morphological characteristics that aid their spread in dry and semi-dry areas, as well as their resistance to decomposition [28], Furthermore, Fabaceae seeds are unpalatable which deter predators [29], Their dispersal is facilitated by sheep herds, as these seeds possess thorns that help them attach to the wool of sheep and spread as the herds move through the valley, The primary value of these seed types lies in their plants' ability to fix atmospheric nitrogen in the soil, even if only for a short period, thereby creating a seed bank in the soil through exposure to wind dispersal processes and water flow in the valley.

Although these plants are considered transient and not perennial because they turn into seeds by the end of summer, upon germination, their roots contribute significantly to an important ecological process, Given the variety of their plant species and their numerical presence in the area, they can be treated as keystone species, especially since they are from arid and semi-arid regions with an unstable ecosystem. Hence, these annual plants pay a major role in these ecosystems by reducing the risk of soil erosion, improving its structure, and increasing its fertility due to these plants' ability to coexist with various types of nodular bacteria that live in a symbiotic relationship with their roots. When soil fertility increases, it enhances the capacity and growth of plants and reduces land degradation. This value is higher than what was found by [14], who reported that the total number of legume seeds was about 10%, and these results are lower than those found by [13] in the Msous desert area, which obtained a proportion of 31% Fabaceae from the total seed types collected. The high proportion of Fabaceae seeds there is likely due to the area having previously been subjected to Fabaceae seed dispersed program as part of pasture development, which was not properly managed and subsequently neglected and degraded, unlike the Valley Al-Sahel Al-Gharbi area, which did not receive any seed broadcasting or pasture development programs.

Morphological Features of the Recorded Fabaceae Seeds:

To complement the quantitative findings on Fabaceae seed density, Figures (6–25) illustrate the morphological diversity of leguminous seeds recorded within the soil seed bank of Wadi Al-Sahel Al-Gharbi. The images demonstrate clear interspecific variation in seed size, shape, coat texture, and pod structure, traits that strongly influence dispersal mechanisms, persistence in soil, and resistance to environmental stress. For example, species of *Medicago* (Figures 12–19) exhibit hardened, spiral or disc-shaped pods that enhance their longevity in the soil and protect embryos from predation or mechanical damage. Similarly, *Astragalus* and *Onobrychis* species (Figures 6–8 and 20–21) possess robust seed coats and indehiscent pods, which facilitate long-term survival under arid conditions.These morphological traits help explain the high proportion of Fabaceae seeds (23.49%) detected in the seed bank, as many of these species produce seeds with physical dormancy and thick testa layers that enhance seed longevity. Additionally, the hooked or spiny appendages found in several species (e.g., *Medicago polymorpha* and *Medicago coronata*, Figures 17–18) allow for epizoochorous dispersal, particularly via sheep and goats moving along the valley, which contributes to the spatial spread of these seeds across lowland and mid-slope habitats.

The photographic evidence further supports the ecological interpretation that Fabaceae species play a keystone role in the regeneration potential of the valley ecosystem. Their morphological adaptations promote persistence in the soil and ensure continuous replenishment of the seed bank despite grazing pressure and seasonal climatic stress. Consequently, the diversity and abundance of Fabaceae seeds shown in the figures reinforce their importance in maintaining soil fertility, supporting nitrogen-fixing vegetation, and stabilizing degraded semi-arid landscapes.

Figure (6): *Astragalus annularis* Forkss

Figure (7): *Astragalus corrgatus* Bertol

Figure (8): *Astragalus hispidulus* DC.

Figure (9): *Hymenocarpos circinnatus* (L.) Siv

Figure (10): *Lotus edulis* L.

Figure (11): *Lotus cytisoides* L.

Figure (12): *Medicago disciformis* DC.

Figure (13): *Medicago laciniata* (L.) Mill.

Figure (14): *Medicago littoralis* Rohde ex Lois

Figure (15): *Medicago minima* (L.) Bartal

Figure (16)*:* *Medicago turbinata* (L).

Figure (17): *Medicago polymorpha* L.

Figure (18): *Medicago coronata* L.

Figure (19): *Medicago truncatula* Gaertn.

Figure (20): *Onobrychis caput*-gali (L.) Lam

Figure (21): *Onobrychis crista*-gali (L.) Lam

Figure (22): *Trifolium tomentosum* L

Figure (23): *Trigonella stellata* Forkss

Figure (24): *Variety muricatus*

Figure (25): *Variety subillosus*

Conclusion:

The present study provides a comprehensive assessment of the seasonal dynamics of the soil seed bank in Wadi Al-Sahel Al-Gharbi, located in the semi-arid Marmarica Plateau of northeastern Libya. The findings reveal substantial seasonal variation in both seed density and viability, reflecting the strong influence of climatic conditions, particularly rainfall seasonality and temperature fluctuations, on seed persistence and regeneration potential. Autumn exhibited the highest seed density and viability due to post-dispersal accumulation, whereas spring recorded the lowest values, coinciding with peak germination periods.

Fabaceae species represented a major functional group within the soil seed bank, accounting for 23.49% of total seeds. Their morphological adaptations, such as hard seed coats, indehiscent pods, and spiny attachments, contribute significantly to seed longevity, soil persistence, and dispersal by animals. These traits highlight their ecological importance in maintaining soil fertility through nitrogen fixation and supporting vegetation recovery in degraded landscapes.

Overall, the study demonstrates that the soil seed bank of Wadi Al-Sahel Al-Gharbi possesses considerable regenerative capacity, despite environmental stresses and human pressures. The seed bank serves as a crucial reservoir for the restoration of vegetation and can play a key role in combating degradation and desertification in semi-arid ecosystems of northeastern Libya.

Recommendations:

- Enhance rangeland management and regulate grazing by implementing sustainable grazing strategies to reduce pressure on vegetation and support natural regeneration.
- Promote the use and conservation of Fabaceae species in restoration programs due to their ecological importance in nitrogen fixation and improving soil fertility in degraded semi-arid environments.
- Implement rainwater-harvesting structures such as check dams to increase soil moisture availability and strengthen vegetation establishment and regeneration.

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