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REVIEW ARTICLE

Role of *Panicum turgidum* Forssk. in arid desert ecosystems: Ecological adaptations and rangeland management

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Abstract

The survival and performance of native desert plants in arid and saline environments is very low, which challenges the biodiversity productivity in these ecosystems. *Panicum turgidum* Forssk. is an efficient option for salt exclusion and possesses greater diversity, which is essential for rangeland development and enhancing biodiversity. This native desert grass exhibits several physiological responses to cope with the harsh conditions, such as drought, salinity and poor nutrient soil habitats that include the seashores, terrestrial desert plains and dunes. It plays an important role in revegetation projects and domestic feeding in arid desert ecosystems. The present review helps in providing an understanding of the ecology and biological processes of *P. turgidum* Forssk. which is crucial for conservation strategies, adaptations and survival in arid environments. Additionally, this review provides insights into the chemical composition and nutritive value of *P. turgidum* Forssk. shedding light on its forage yield and palatability. More significantly, its biological activities and importance in rangeland management within arid desert ecosystems of the Arabian Peninsula, including Kuwait, are explored. Optimizing agronomic practices is crucial for reducing soil salt, drought stress, harvest issues and its contribution to sustainable ecological functions and rangeland management. The key challenges and valuable suggestions for future research directions are also addressed.

Keywords: biological potential; chemical composition; livestock feed; palatability; rangeland management

Introduction

Desert ecosystems are biodiverse habitats that vary depending on a number of environmental factors. Many arid regions, including Kuwait and the Arabian Peninsula, present a number of environmental difficulties that set boundaries for biodiversity and agricultural productivity. The arid desert ecosystems of Kuwait face multiple environmental challenges, such as prolonged drought, limited rainfall, high soil salinity, extreme temperatures, intense sunlight, low moisture retention and poor soil fertility (1). This necessitates search of resilient plant species that exhibit the potential to grow in arid and saline environment with scanty rainfall. *Panicum turgidum* Forssk., commonly called as 'thumam' in Kuwait and other Arabian countries stands out as a candidate grass to survive amidst the harsh desert landscapes of the Arabian Peninsula (2-4). This perennial plant is from Poaceae family (5). It inhabits rocky areas, dunes, seashores, semi-deserts, as well as sandy deserts in Middle East, Asia and Africa (6). Adaptability of this plant to adverse climatic conditions has made it a potential and preferred fodder crop in Kuwait and other Arabian Peninsula countries (7). More importantly, *P. turgidum* Forssk. is known to have high nutritive value and there are several ecological significances of this native desert grass, which is recently gaining sight of many researchers (8, 9).

P. turgidum Forssk. is a nutrient rich, salt excluding fodder grass, with an acceptable palatability in the livestock (3). This forage grass along with other native grass species provides sustenance to grazing livestock in resource limiting regions like Kuwait desert ecosystems (10). In arid areas with salty and brackish water supplies, the production of salt-tolerant fodder crops, such as *P. turgidum* Forssk. can offer a solution with a prolonged low water supply or nutrient poor soils (3, 11). Despite harsh environment, this plant has a trait of high biomass production with a nutritional value of biomass comparable to conventional forage species (8). There are evidences of *P. turgidum* Forssk. to be rich in bioactive metabolites with flavonoids being the predominant class (12). Beyond the application of forage, this plant is proven to have a significant role in soil conservation and restoration of rangelands in Kuwait and other arid regions (13, 14). Available reports highlight the importance of this desert grass within the arid land ecosystems (14-16) (Fig. 1). The deep penetration of roots into soil, along with the effects of soil health, water resources and biodiversity on the plant growth, aids in conservation efforts. Combining plant production with landscape approaches can increase ecosystem flexibility and a probable synergistic growth. Nonetheless, the genetic diversity of *P. turgidum* Forssk. is important for conservation, rangeland development and breeding efforts (17). The optimization of agronomic practices for the cultivation of this plant can lead to the

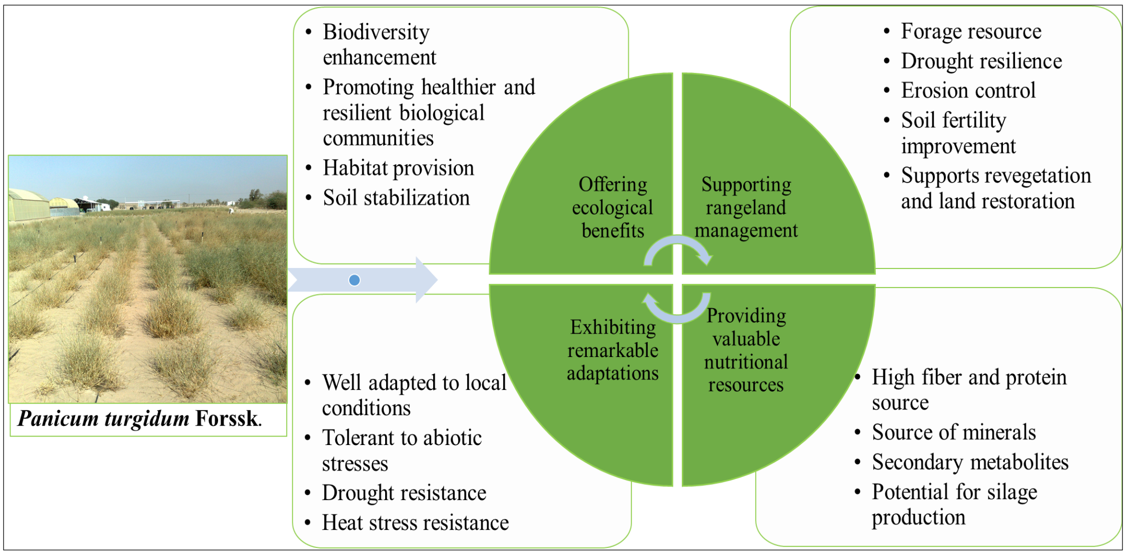

Fig. 1. Importance of *P. turgidum* Forssk. (thumam) in arid desert ecosystems (14-16).

increase in the productivity as well as resource efficiency. Studying the intercommunication of this native desert grass with beneficial microorganisms can help water absorption, nutrient uptake and soil health (18). Meanwhile biomass production holds promise for bioenergy and biofuel applications, requiring specific breeding and processing techniques. Understanding the broader ecological impacts of cultivating this plant is crucial for sustainable land management. However, further research is required on the farming technology adoption of this species, agronomic techniques, vegetative or seed-based propagation and their impact on forage or seed production.

This review highlights the biology and the ecological adaptations of this native desert grass, along with the function of rangeland management and animal feed. It also highlights different challenges within arid desert ecosystems that include environmental conservation, biodiversity productivity, as well as sustainable fodder in arid regions. Attempts have been made to shed light on its chemical composition, biological potential, nutritive value, seed and forage yield, palatability and the significance of *P. turgidum* Forssk. in rangeland management and sustainable development. Research efforts should investigate identifying stress tolerance genes together with implementing novel breeding strategies like genomic selection to help the adaptability of this grass. The genetic diversity and practical uses of this native desert grass are being explored, indicating its promising role in improving the well-being of arid regions and their inhabitants. Furthermore, as climate change increases environmental stresses, there is a growing need to produce *P. turgidum* Forssk. varieties that are resistant to drought, heat, as well as salinity. More importantly, this review brings light on several aspects worth for the rangeland development in Kuwait, the Arabian Peninsula and other arid regions.

Plant biology and ecology

P. turgidum Forssk. is an essential component of desert ecosystems. This plant can withstand and even thrive in dry and salty environments because of its unique morphological and physiological adaptations (19). The stems of this grass are characterized by their long joints, hardness and polished appearance with roots at the nodes and few leaves and inflorescences (20). The leaves are linear-lanceolate, stiff and often shorter than the sheath. The inflorescence is moderately branched, pyramidal panicle, with spikelets that are ovoid and often gaping at anthesis. Lower florets are male, while upper florets are bisexual (21). The plant has a widespread and deep penetrating root system with fine root hairs (22). It is known to grow in dense bushes and is a drought-resistant C4 plant, exhibiting rapid growth during late spring and summer. Successful seed germination occurs under higher temperatures, while transplant propagation is best done during moderate temperatures to prevent water loss. The growth of this plant is significantly influenced by water availability, with increased biomass, tillering capacity and seed output observed under optimal water conditions (8). The emergence, survival and establishment of *P. turgidum* Forssk. seedlings are crucial factors for maintaining and restoring vegetation cover. In arid and semiarid ecosystems, the survival of seedlings depends heavily on soil water availability. The successful germination of this plant requires specific conditions, including temperatures (25-35 °C) and adequate water supply, which are often rare in the desert regions of Kuwait and other Arabian countries (14, 23). These arid desert ecosystem regions are distinguished by extreme temperatures, low and infrequent rainfall and prolonged drought (24). Consequently, seedlings of the plant are infrequently found in desert ecosystems conditions, with the species primarily relying on vegetative reproduction by cuttings for propagation. The reproductive ecology of *P. turgidum* Forssk. provides the suitable methods and time for propagation of this native desert grass within the arid Arabian desert ecosystem (23). The plant is also known to have higher innate dormancy (25). The growth and metabolism of this plant was observed to correlate with several physiological parameters, including chlorophyll content, antioxidants and hormone production, transpiration, water use efficiency, regulation of stomatal function, net photosynthetic rate, electron transport rate and leaf-to-atmosphere temperature gradient that makes this plant survive in desert and arid climates (1, 26, 27).

P. turgidum Forssk. is highly drought-tolerant and can thrive in regions with minimal annual rainfall. It grows in sandy deserts and semi-deserts, on dunes, seashores and in sandy pockets among rocky outcrops, with an altitude range up to 3200 m. This species plays a vital role in desert ecosystems, stabilizing sand and forming hummocks, often forming dense stands. In Sudan, it dominates areas where locusts lay their eggs and serves as food for young locusts. Additionally, this plant demonstrates tolerance to saline soils and has robust roots and root fibers that are very strong. Its root hairs excrete viscous materials, allowing them to adhere to fine sand particles, enhancing moisture absorption from the soil. This species thrives in deep dunes and well-drained soils, making it valuable for stabilizing dunes (28). Under saline conditions, this plant is known to exhibit increased production of reactive oxygen species (ROS), leading to oxidative stress and photodamage. The plant experiences no significant decrease in chlorophyll content or increase in non-photochemical quenching, indicating sustained electron flow through photosystems under higher salinity conditions (27). It has been reported that in plants, there is a positive correlation between growth inhibition and increased lipid peroxidation levels under salinity stress. While gas exchange decreases, intercellular CO_2 concentration remains stable, suggesting reduced carboxylation activity of photosynthesis without CO_2 starvation. The decline in gaseous assimilation rate is potentially related to reduce Rubisco activity (27). It is also known that *P. turgidum* Forssk. has efficient ability to tolerate drought stress (29). As per the available reports, C4 species exhibit significantly higher water use efficiency compared to the C3 species (30, 31). This grass has the strongest adaptation to water shortage with down-regulation of photosystem II, which aids in enduring water shortage and facilitating recovery. Up-regulation of dehydrin 1, a plant protein also occurs under drought stress in this grass (32).

Adaptations and importance in the arid desert ecosystems

Kuwait's native floras, including many native grass species, are currently at risk of extinction due to uncontrolled extended drought periods and the advancing desertification (10). These factors have significantly reduced the presence of these native grasses in the desert rangelands. *P. turgidum* Forssk. has evolved as a perennial grass of arid regions of the Arabian Peninsula, despite several environmental constraints and the challenges in the desert ecosystems. Its adaptation to survive under limited rainfall and high grazing pressure makes it a valuable grassland species and a potential solution for rehabilitating degraded rangelands (33). In most of the Arabian Peninsula countries, especially in Kuwait, hot desert ecosystems, *P. turgidum* Forssk. exhibits a preference for habitats characterized by depressions and shallow wadis, where the soil composition tends to be more coarse-textured, sandy and gravelly (24). It also survives on slopes (3). The adaptability of this plant corresponds to reduced leaf area, extensive root system, waxy leaf coatings and pubescence to minimize water loss through transpiration and protect against radiation stress (14, 34, 35). An earlier study identified genes with various functions and pathways, including those related to abscisic acid synthesis, signal transduction, osmolyte synthesis, protection of macromolecules, cell wall remodelling and drought-induced dormancy that help in regulating water stress in this plant (36). The *Panicum* genus has greater genetic variability, attributing to different agro-morphological characters (37). *P. turgidum* Forssk. also shows larger genetic variation within varieties, which can be a probable reason for greater adaptability in biotic stress without human intervention (38). These findings underscore the significance of this plant as a resource-efficient and drought-resistant grass species (7). It offers promise in reducing the reliance on irrigation in Middle Eastern North African (MENA) regions, making it a crucial candidate in the sustainable management of arid ecosystems and the restoration of degraded rangelands (39).

Plants like *P. turgidum* Forssk. provides an opportunity for agro-based development in the MENA regions. Additionally, this plant demonstrates an increased water use efficiency under moderate drought stress (27). This means that even in challenging conditions, it can make the most of available water resources, contributing to its survival. *P. turgidum* Forssk. plays a vital role in addressing the environmental challenges of arid ecosystems of Kuwait by trapping moving sand into nabkhas (40). In these harsh environments, plants face a multitude of stresses, both biotic and abiotic, including drought, heat and salinity (1, 41). To survive and thrive, this plant has developed a range of adaptive and defensive mechanisms on cellular, physiological, metabolic and molecular levels (42). One key adaptation involves the regulation of photosynthesis, particularly in response to drought stress. *P. turgidum* Forssk. exhibits a competitive advantage over C3 plants by employing the C4 photosynthetic pathway (32). This mechanism allows *P. turgidum* Forssk. to maintain photosynthesis rates even when stomata, responsible for gas exchange, close to conserve water (43). This is in contrast to C3 plants, where the decrease in stomatal conductance leads to a decline in photosynthesis rates (44). This plant emerges as a lucrative cash crop option, particularly well-suited to thrive in low-quality soils with moderate salinity levels. Leveraging its sustainable cultivation not only offers economic benefits but also holds potential for land reclamation and desalination efforts, alongside contributing to carbon dioxide sequestration (27). The potential for increased seed production further solidifies its role in these critical environmental efforts. Overall, the adaptations of this plant make it a crucial plant in mitigating the environmental constraints of arid ecosystems, offering insights into the resilience of plant life in the face of adversity.

Potential as sustainable livestock feed in arid habitats

In the Arabian Peninsula countries including Kuwait, the hot and arid climate along with poor soil fertility and low moisture retention reduces the options of fodder cultivation, where *P. turgidum* Forssk., stands out as a promising candidate crop (1, 9, 18, 45). The key character of this plant is salt exclusion, which reduces the issue of excessive thirst in sheep, goats and camels after feeding. In most of the arid and semi-arid Asian countries, alfalfa, Rhodes and maize are very prevalent fodder crops, but the fodder yield is hampered by salinity (46). Animal feeding trials replacing maize with *P. turgidum* Forssk. have shown equivalent growth and meat production, highlighting its potential economic viability (3). In the absence of fresh water, *P. turgidum* Forssk. yield is also obtainable using brackish water (3). Despite variation in nutritional composition relative to geo-climatic changes, *P. turgidum* Forssk. fodder is a good balance of fiber and protein. This review suggests that *P. turgidum* suits best as admixture with other fodders, whose ratio is yet to be optimized. Mixing of fodder is evident, since browsing feeders tend to prefer varied vegetation as fodder.

Being a salt excluder, this plant does not contribute to salinity reduction. Hence, successive cropping in the field using saline water is unadvisable for sustainable harvest. Growing *P. turgidum* Forssk. with salt accumulating plant like *Suaeda fruticosa* L., offers a viable alternative (3). This system demonstrates sustainability in terms of soil salt balance, where one plant reduces the salt, whereas the other provides fodder, generating a minimal change in soil salinity. Strip cropping can also aid in sustainable cropping to keep the salinity in control (47). Natural phenomena like nebkhas can also provide a natural alternative to sustainable plant growth and vegetation development (48). There is a need to research on agronomic practices for sustainable improvement in fodder yield of this plant in arid regions and desert ecosystems.

Chemical composition and nutritive value

P. turgidum Forssk., known for its high nutritional value, reflects how the nutritional quality of forage plants is influenced by their protein, lipids and carbohydrate content (8, 9). However, the palatability and digestibility of each plant is also determined by the composition of these organic nutrients, along with minerals, vitamins and antinutritional compounds (49). In case of *P. turgidum* Forssk., high crude protein percentage (7.6 % and 12.06 %) that exceeded the minimum required for grazing animals (6 %), indicating excellent forage quality was reported (9, 50). A significant amounts of crude fiber (13.84 %) and high lipid content (5.87 %) was seen in this grass (50). Crude protein (CP) and crude fiber (CF) are considered key indicators of the nutritional quality of forage for grazing animals (51, 52). The total digestible nutrients were also high for this plant, indicating the energy available in food for animals after the digestion. *P. turgidum* Forssk. does not contain high levels of salt, harmful organic constituents, or secondary metabolites in the harvested foliage and other parts of the plant. The concentration of nutrients (Na, Ca, P) in the grazeable parts of *P. turgidum* Forssk. populations from Egypt showed insignificant variability across habitats and phytogeographical regions, whereas significant differences in potassium concentration varied (9). The Ca/P ratio in this plant was significantly associated with soil silt and organic matter content. The ash content was found to be 8.62 % (50). The ash content, mainly composed of sodium and chloride (13 %), is not prohibitive for consumption and may reduce the need for salt licks for cattle (50). Compared to other local halophytes, oxalate levels are lower (4.14 %) and water-soluble forms are easily metabolized by animals (3). Additionally, grazing plays an important part in the increase of the nutritive value of the grasses by promoting a higher ratio of new growth to old growth. Grazing also helps in removing or preventing the build-up of thatch and reduces the accumulation of dry old shoots, which can hinder new growth (53). With its high nutritive value and easy cultivation, the grains from this plant could serve as a potential supplementary food alongside common cereal.

This plant exhibits potential biological activities attributed to its phytochemical composition. The presence of phenolic compounds, flavonoids, macro and micro minerals in the extracts from *P. turgidum* Forssk was identified in a previous study (50). Phytochemical analysis of *P. turgidum* Forssk. extract led to the isolation of three steroidal saponins (54). A comprehensive analysis identified 39 metabolites in the crude extract of this plant, with flavonoids being the predominant class, including O/C-glycosides of luteolin, apigenin, isorhamnetin and naringenin (12). In another study, the methanolic extract of the plant yielded three new bidesmosidic cholestane-type steroidal glycosides, along with four other compounds (55). Phytochemical analysis of the aqueous extract revealed the presence of alkaloids, flavonoids, tannins and saponins (20). Seven steroidal saponins, named Turgidosterones 1-7, are reported to be isolated from *P. turgidum* Forssk. extract (56). Antinutrients, also known as antinutritional factors, are the plant compounds that hinder the intake, digestion, absorption and utilization of nutrients, often leading to adverse effects in animals (57). There are reports of the production of some anti -nutritional components like hydrogen cyanide and tannin in the *Panicum* genus like *P. maximum* in the growth stages of the plant, however these anti-nutrient constituents are found in low levels (58). Lower levels of tannins are reported to have no negative effects on the energy digestion rates, crude protein and consumption rates of tested halophytes (59). The same author reports that low levels of tannins react with crude proteins and increase the feed value of halophytes. In case of *P. turgidum* Forssk. quantification studies need to be done to examine the levels of anti-nutritional components.

Palatability

Animal preferences play a significant role in determining the palatability of this plant. Different livestock species exhibit varying preferences for the fodder grass, depending on factors such as species-specific feeding behavior, previous exposure to the plant and nutritional requirements (60). The palatability of the leaves of *P. turgidum* Forssk. is sufficient for camels and donkeys, whereas for sheep and goats in their younger age. The proper grazing management strategies, such as rotational grazing and supplementing with other forage species, can help enhance the palatability and utilization of this plant by livestock (61). The sheep preferred forage combinations that included *P. turgidum* Forssk., especially when mixed with *Leucaena leucocephala*, probably due to higher protein content in the combination, which is crucial for the diet of ruminants like goats (62). Cattle would prefer palatable grasses, but sheep and goat are found to have higher salt tolerance and hence are largely used in trials of *P. turgidum* Forssk. as fodder (3). In a cattle feeding trial in Pakistan, *P. turgidum* Forssk. was used as a replacement for maize and the results obtained showed equivalent growth and meat production (3).

Functional nutritive value and palatability of this plant is greatly influenced by environmental factors, variable across season and optimal for only a short duration annually (63). Drought stress and fertilizer deficiencies can lead to decreased palatability and nutritional quality of this grass. Conversely, optimal growing conditions with adequate moisture and soil fertility can enhance palatability and nutritive value. While the carbohydrates (approximately 59 % in fresh condition) and other biochemicals in *P. turgidum* Forssk. regulate the palatability, the variation after drying (approximately 80 % carbohydrates) can be compensated by blending supplements to adjust the palatability (49). The importance of soil moisture and management in improving forage quality and palatability of *P. turgidum* Forssk. in arid environments has been reported (64). In general, potential intake rate and relative preference are main indices of palatability, where it was found that *P. turgidum* Forssk. to have nearly 75 % relative preference as compared to other grasses (65). It has also been reported *P. turgidum* Forssk. to be moderately palatable compared to other grasses in arid regions (66). It would be quite essential to prioritize the research on palatability controlling genes in this plant to improve the preference among livestock for grazing purpose. There is a greater knowledge gap regarding expression analysis and genes regulating the metabolism of palatability controlling traits in this plant. The animal fodder, preference cost of research using animals and lack of candidate factors controlling palatability are real challenges in breeding this grass.

Forage yield

The plant is known to yield up to 60 tons/hectare/year of fresh matter with plant survival rate of 60 % when cultivated in saline soil (EC 10-15 mS/cm) irrigated with brackish water (EC 10-12 mS/cm) in Pakistan (3). When grown in association with *Suaeda fruticosa*, it helps mitigate the risk of soil salinization that typically occurs when cultivating desert grass alone in areas irrigated with brackish water. However, by implementing optimized cultural practices such as proper irrigation, fertilizer or farmyard manure application and closer plant spacing, further increases in yield are possible (67). The plant is known to be a high-quality fodder grass for the coastal Pakistan and might be suitable for the other tropical regions. Another study on forage yield suggested that *P. turgidum* Forssk. can tolerate higher salinity levels and still produce considerable forage biomass with yield showing 1279.79±16.59 g/drum (Fresh weight) when harvested annually under 30 % seawater irrigation (EC: 14.0 dS/m) while it was 2851.85±57.83 g/drum (Fresh weight) in the control with lower salinity (1.2 dS/m), resulting in a reduction of approximately 55 % (68). For 10 % and 20 % seawater irrigation, the reduction in forage production compared to the control was around 23 % and 34 %, respectively. Despite the reduction in biomass, the plant exhibits continuous flowering throughout the year. This suggests that while there is a significant reduction in yield as salinity increases, highlighting the importance of managing soil salinity for optimal production. In Egypt, *P. turgidum* Forssk., offered a fresh yield of 30 t per hectare and contributed 0.800 t of crude protein and 0.433 t of digestible crude protein (62). It is reported that 1 ha of this grass can support 56 goats for a year. During the spring planting season, *P. turgidum* Forssk. exhibits greater dry matter production indicating its suitability for forage yield in arid regions of the Arabian Peninsula, such as Kuwait (8). It is recommended that the seed rate for sowing should be 200 g/ha (7). The data of the forage yield from different geographical locations indicate that the foliage yield is relative to the geoclimatic conditions and genotype of the plant. In case of commercial farming, the forage yield using freshwater has not yet been studied. Hence the genotypic potential of forage yield is yet unknown. Little is known regarding the relationship between plant spacing and its impact on tillering and the quantitative trait loci for forage yield in this plant.

Biological potential

P. turgidum Forssk. contains a diverse array of phytochemicals and bioactive compounds, which are largely responsible for its extensive biological activity. These include various classes of secondary metabolites such as saponins, flavonoids and glycosides (56, 12). Overall, the rich phytochemical profile of this plant enhances its medicinal value, making it a crucial plant for pharmacological research. Available reports indicate that it shows notable anticancer (69, 19). There are also reports that indicate its antifungal, antibacterial, anti-inflammatory, antipyretic and antioxidant effects (19, 20, 54-56, 70-73). Additionally, this plant shows antileishmanial and antitrypanosomal activities attributed to its steroidal saponins (56). A recent study reported that *P. turgidum* Forssk. harbors the most diverse fungal species, these culturable fungal communities represent a unique source of bioactive compounds that can address the current challenges in drug discovery (74). Table 1 provides the detailed information about the potential biological activities of this native desert grass. These biological activities collectively highlight the importance of this plant in medicinal contexts, offering significant benefits for human health. Furthermore, it is reported that native desert plants including *P. turgidum* Forssk. produces a range of secondary metabolites with important physiological and ecological impacts as a means of self-defense from external abiotic limitations (12, 27, 75). These substances, which include phenolic acids and flavonoids, help this grass withstand harsh conditions. According to one study, *P. turgidum* Forssk. has 39 metabolites, with flavonoids such as luteolin, apigenin, isorhamnetin and naringenin glycosides being the most common (12). Plants frequently alter the synthesis of secondary metabolites as a defensive mechanism when faced with abiotic stressors. It has been reported that the metabolite profile of *P. turgidum* Forssk. is affected by exposure to salt stress, resulting in modifications to the amounts of the primary and secondary metabolites (27). By maintaining cellular homeostasis and guarding against oxidative damage, these changes help the plant in lessening the negative consequences of multiple stresses (27, 75).

Genetic diversity

Study of genetic diversity in *P. turgidum* Forssk. aids in effective resource management and restoration of new lands without compromising adaptation and genetic diversity. This plant exhibits a wide geographical distribution, spanning diverse habitats ranging from arid and semi-arid regions to more temperate climates. Populations of *P. turgidum* Forssk. are found across different continents, including Africa, Asia, Europe and North America (6, 76). The combination of rbcL and matK markers provided a comprehensive overview of the genetic diversity and phylogenetic relationships within

Table 1. Biological activities of *P. turgidum* Forssk. (thumam).

Biological Activity	Activity Range	References
Anticancer	IC$_{50}$ value (µg/mL) MDA-MB-231 cancer cell line (77.59) HCT116 cancer cell line (16.82)	(19)
Antibacterial	*S. mutans. S. aureus, K. pneumonia, E. coli* MIC & MBC value (0.8 & 0.72 mg/mL)	
Anticancer	IC$_{50}$ value Ovarian carcinoma (5.65±0.31 µg/mL) Breast carcinoma (10.3±0.56 µg/mL)	(69)
Antihepatotoxic	-	(12)
Antibacterial	MIC range (mg/mL) Gram-negative bacteria (9.4-37.5) Gram-positive bacteria (18.8-37.5)	(71)
Antibacterial Antifungal	Zone of Inhibition (mm) *Streptococcus pyogens* (18) *Candida albicans* (18)	(20)
Anti-inflammatory	IC$_{50}$ value (µM), Compound 1 (16), Compound 2 (2.1), Compound 3 (8.6)	(54)
Antioxidant	EC$_{50}$ value of 0.93 mg/mL 52.31 % scavenging activity at 1 mg/mL	(50)
Cytotoxic	-	(55)
Antioxidant	IC$_{50}$ value of 107.88±2.23 µg/mL	(73)
Antifungal	IC$_{50}$ value (µg/mL) Compound 5 *C. albicans* (10.83), *C. neoformans* (14.51) Compound 6 *C. albicans* (2.84), *C. neoformans* (1.08)	
Antileishmanial	Compound (4-7) *Leishmania donovani* promastigotes (4.92 to 8.04 µg/mL) *Leishmania donovani* amastigote/THP (4.51 to 9.29 µg/mL)	(56)
Antitrypanosomal	*Trypanosoma brucei* (1.26 to 3.78 µg/mL)	
Antipyretic	-	(72)
Antifungal	Fungi *Botrytis cinerea* BC21 (98 % inhibition) *Fusarium graminearum* g1 (42 % inhibition)	Guesmi et al. (70)
Antibacterial	Bacteria *Staphylococcus pasteuri* PT2 and *Acinetobacter baumannii* PT6	

Panicum species (77). Additionally, the ndhF marker was identified to be useful for grass phylogenies due to the availability of a high-quality dataset in African grasses. The genetic diversity of 177 different samples of *P. turgidum* Forssk. from ten populations across four regions in Saudi Arabia marked distinct diversity in this plant, based on geographical sources, where central Arabia had greater genetic diversity. This was supported by a significant correlation of genetic and geographical distances between these diverse grass populations (17). The germplasm from Palestine and adjacent areas could act as donor germplasm for improved agronomic traits and recommends crossing them with one found in the Middle Eastern region (78). This was later proved from the experiments on forage and seed yields (22). The genetic traits regulating drought resistance vary with geographical distribution as well (3).

The increased drought severity in arid deserts challenges ecosystem restoration and crop production, it also affects native seed germination, seedling growth and establishment in the natural desert ecosystems (10). The only data on differentially expressed genes in *P. turgidum* Forssk., highlighted 108 functional and 179 regulatory genes regulated in drought conditions (36). The genes that regulate drought resistance in this plant include those involved in abscisic acid synthesis, signal transduction, osmolyte synthesis, protection of macromolecules, cell wall and cuticle remodelling and drought-induced dormancy. Additionally, some functionally annotated orthologs that have not been previously reported as drought responsive yet were commonly upregulated in *P. turgidum* Forssk., including a chaperone located in the endoplasmic reticulum and an oil body-associated gene. These genes play a crucial role in the drought stress response and contribute to the higher drought tolerance of this plant. Comparative genomics, genome-wide association studies, differential expression of genes are essential to find the association of genes regulating the qualitative and quantitative traits in this plant. This in turn would help in understanding the diversity. The sequence data on genotypes of *P. turgidum* Forssk. from most of the Gulf countries, including Kuwait, is missing and needs to be studied at large.

Rangeland establishment and management

Kuwait spans an area of 17800 km^{2}, including dunes (with nebkhas) and 5093 km^{2} of sand sheets cover (79). The rangeland of Kuwait has low humidity, scanty rainfall and sparse vegetation, predominantly occupied by woody shrubs (80). The rangeland vegetation dynamics of Kuwait from 1979 to 1989, concluded a decline in species diversity by reduced rain, topsoil loss by wind erosion and loss or burial of viable seedlings in topsoil erosion (81). Similar issues of rangeland deterioration are faced by many arid regions (82, 83). Many rangeland management plans have been unsuccessful, which had an introduction of new plant species, issues of unbalanced grazing to production regime or heavy metals in plants post-gulf war (84, 85). The research on the effect of climate change on desert ecosystems and the integrated study of microbes on the rangeland vegetation is recently initiated (86).

There are many reports on rangeland management, but there is a severe deficit on a report of successful and sustainable rangeland development trials. A report on development of strategies for rangeland development and divided the concept into 6 sections (87). It included forage allocation, inventory of rangeland resources, specialized grazing systems on the use and value of rangeland, manipulative range improvements, applying socioeconomic techniques to range management decision making and finally, legal and political aspects of range management. Multiple reports end up highlighting major issue of intensive grazing leading to failure in rangeland development. Some other reasons are lack of funds or incomplete restoration efforts (88). The information for successful rangeland establishment is segregated and needs to collect and redesign a strategy for optimal operational procedure for *P. trugidum* growth in Kuwait or other similar arid rangelands.

The subsequent challenge is establishing suitable sites for growth of this plant. In arid lands, the conception of "Fodder Banks" emerges as an ideal solution. This concept involves establishing blocks of fodder trees alongside grasses and legumes, facilitating the cultivation and storage of dry fodder (5). Additionally, it encompasses practices such as haymaking, baling/densification and transportation of fodder to meet the needs during lean periods. Data on identification of soil types in Kuwait; the authors provided an approach to restore rangelands in Kuwait, the area where there is a need to contribute to revegetation success by targeting the planting of suitable plant communities (89). The soil with higher soil electrical conductivity is also suitable for *P. turgidum* Forssk. growth in Kuwait (25). This plant acts as an ideal nurse plant, aiding growth of other diverse plant species in its canopy (90). The growth of this plant is influenced by salinity and hence a low salinity irrigation, sowing in early March is crucial for establishment (68). Comparing various perennial native desert grasses establishment including *P. turgidum* Forssk. in two planting seasons *i, i.e.,* fall and spring, the authors report that the fresh and dry weight in case of *P. turgidum* Forssk. is higher during the spring season planting (8). The survivability of this plant in rangelands is challenging. Surprisingly, we did not find much research related to plant pathogens affecting *P. turgidum* Forssk., which is an important issue in extensive farming.

The scheme of protecting areas from grazing impacts may not be sufficient for rangeland improvement. Continued long-term research in arid rangelands of Kuwait is recommended, focusing on establishing permanent enclosure plots in areas of sparse desirable species and less grazing pressure to monitor vegetation succession and trends in relation to climatic variables (80). Seed-based propagation with seed treatments to reduce dormancy or vegetative propagation has to be tested (91). *P. turgidum* Forssk. is wind dispersed and needs human intervention of controlled sowing in close proximity of the irrigation source for rangeland management. The report also added the need for studying the irrigation regime in seasonal changes (43). Many attempts of rangeland improvement are not successful due to an imbalance in grazing to forage yield. Intensive stocking has resulted in lesser yield, high weeds and undesirable plants in rangelands (92). Long term grazing also results in a reduction in the performance of rangelands (45). Land degradation can accelerate due to human activities and livestock grazing and when compounded by drought, the combined impact of these factors can lead to catastrophic consequences within the Arabian Peninsula countries, especially in Kuwait (81). The only solution to limit the grazing activity during the growing season is spanning 6 months in desert rangelands of Wadi Hederbah in Southeastern Egypt, with grazing intensity of only 35 % forage use for a sustainable rangeland management (93). This holistic approach not only ensures a diverse and sustainable fodder supply but also enhances resilience to environmental fluctuations, thereby mitigating the impact of adverse conditions on livestock feeding.

Some hypotheses were proposed such as rotational grazing, incentivizing people for planned rangeland utilization, selective livestock that are efficient grazers to the given niche, negatively incentivized overgrazing, getting involvement of local population for implementation of restoration schemes and regulations for rangeland development (94). Building contour bunds, micro-catchments, native species reseeding, strategic placement of salt licks to encourage controlled grazing patterns, Geographic Information Systems (GIS) and using the drone technology for monitoring vegetation dynamics, assessing rangeland health and identifying areas for targeted interventions were also proposed (79, 94, 95). This effort should be encouraged by involving non-governmental organizations and community knowledge dissemination to adopt sustainable land management practices in areas, which need to be worked upon for rangeland development and restoration in Kuwait.

Challenges and future perspectives

The water crisis in Kuwait showed a forecast of 0.265 m^3 per capita per dayto keep up with urban requirement, with a burden of mere 120 mm annual rainfall (96). This is the prime challenge for the implementation of the agricultural research project in Kuwait. To meet the water needs, the only available options at present or in the future are fresh to brackish groundwater, desalination of available water resources and treated wastewater. The available reports show that due to the expansion of the agricultural areas in Kuwait, mainly in Wafra, has led to excessive pressure on the groundwater resources (97). To solve these complicated issues, there is a need to implement agricultural practices and establish a farming system using "water saving plants" by adopting native desert plants that have the potential to be cultivated as fodder and crops (8). Trial of *P. turgidum* Forssk. along with native plant species to reduce soil salinity, reduce evaporation of water from soil, dense cropping, etc., should be carried out.

Growing population is consequent to reduction in arable land, reduced resources, lesser water availability and increased food and fodder requirements (98). The global milk production in arid and hot climate regions is going to reduce consequent to reduced fodder production and lower profit ratio due to higher maintenance cost (99). The preference of livestock as food does not seem to have decline, but is increasing every year. This necessitates the improvement in fodder yields and alternatives to increase arable land with indigenous fodder crops adapted to saline and dry soil. However, these fodder sources require significant quantities of good-quality water and agricultural land, often competing with food crops for human consumption. *P. turgidum* Forssk. has potential for creating drought-resistant green spaces, where other fodder crops would seldom be grown. It is a candidate crop in sustainable agriculture, medicinal applications, urban landscaping and conservation. However, lesser information is available on conservation efforts and preserving the overall ecosystem well-being. A significant knowledge gap remains in understanding the molecular mechanisms attributing to *P. turgidum* Forssk. stress tolerance and ecological resilience. While some insight exists into its physiological adaptations, further research is needed to study its genetic basis. Investigating putative genes and pathways could inform strategies for crop improvement and ecosystem management. *P. turgidum* Forssk. has not yet been studied for antinutritional factors like tannins and hydrogen cyanide content, which generally are found in *Panicum* genera (58).

As climate change intensifies environmental stresses, developing *P. turgidum* Forssk. varieties resilient to drought, heat and salinity becomes increasingly important. Optimizing agronomic practices for *P. turgidum* Forssk. cultivation can enhance productivity and resource efficiency. This desert plant has a potential for addressing multiple challenges in arid ecosystems of the Arabian Peninsula, including Kuwait and other arid regions in the near future. The identification of the stress tolerance genes that are related to drought, salinity and heat is one important direction. Identifying these genes will enhance the resilience of *P. turgidum* Forssk. in extreme desert conditions. Furthermore, the use of molecular markers associated with the genome of this desert grass together with the molecular level studies focusing on the DNA sequences can provide valuable insights into the genetic makeup of this plant. Establishing seed production techniques together with the development of mass propagation methods is important for large-scale restoration projects in arid places. In addition, it requires determining the optimal nutrient requirements and water use efficiency for increasing biomass production in arid environments of Kuwait, both the optimal nutrient requirements and water use efficiency are very important for restoration and forage production efforts. To enhance the growth and stress resilience, it is important to explore the relationship of *P. turgidum* Forssk. with the microbial symbionts. The microbial profile of irradiated roots of this plant sheds light on the resilience of *P. turgidum* Forssk. microbes and their adaptive strategies in extreme desert conditions (100). Another investigation identifies the genetic diversity of the Arbuscular Mycorrhizal Fungi (AMF) community in association with the native desert plant roots of *P. turgidum* Forssk (101). The study highlights the symbiosis and host specificity of AMF and validates their extensive diversity (101). More importantly, assessing the quality of the feed, its digestibility and palatability for livestock can pave the way for use of this plant as a valuable forage crop in Kuwait and other arid areas. Additionally, this native desert plant may be preferred for restoration projects as it is well adapted to local conditions and can help restore natural habitats effectively. Finally, examining the phytochemical composition and biological potential of this plant may reveal its potential as a therapeutic plant.

Conclusion

P. turgidum Forssk., with diverse ecological, agricultural and biological potential, has remarkable resilience in arid environments. Its multifaceted uses, from dune binding to cultural and medicinal applications, make it a candidate crop for afforestation and livestock feeding in such ecosystems. Despite challenges spanning from biotic stress to cultivation with limited genetic discoveries, the grass's genetic diversity remains important for conservation and breeding efforts. Notably, its fodder potential, high yield and preference in livestock, combined with the integration of gene pool in production of drought-resistant plants provides a roadmap for rangeland development. Understanding the broader ecological impacts of *P. turgidum* Forssk. cultivation is essential for sustainable land management, emphasizing the need for further research on its effects on soil health, water resources and biodiversity to support conservation efforts and promote ecosystem resilience. In many arid regions like Kuwait, *P. turgidum* Forssk. offers a possibility of rangeland management and sustainable generation of fodder, livestock rearing, milk production, employment and help in circular economy.

To conclude, using drought, heat and salinity resistant varieties of *P. turgidum* Forssk. is much important in the face of climate change in the Arabian Peninsula. To enhance the resilience of this desert grass, identification of stress tolerance genes, optimizing agronomic practices and exploring microbial symbiosis is much needed. Improving water use of this plant and establishing efficient seed production will prove helpful in restoration efforts. The potential of *P. turgidum* Forssk. as livestock feed and a therapeutic plant adds further value in the arid regions of the Arabian Peninsula like Kuwait.

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Authors' contributions

TAM and SS contributed to conceptualization and writing of the manuscript. TAM contributed to reviewing, editing and revising. TA and HM contributed to validation of the manuscript. All authors have approved the final draft of the manuscript.

Compliance with ethical standards

Conflict of interest: There are no conflicts of interest to declare.

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References

1. Madouh TA. Eco-physiological responses of native desert plant species to drought and nutritional levels: Case of Kuwait. Front Environ Sci. 2022;10:785517. https://doi.org/10.3389/fenvs.2022.785517
2. Adam AAG. Prevalence and nutritive value of some arid range plant species in Raniah Province of Makkah district. J Nat Sci Res. 2015;5(16):137–41.
3. Khan MA, Ansari R, Ali H, Gul B, Nielsen BL. *Panicum turgidum*, a potentially sustainable cattle feed alternative to maize for saline areas. Agric Ecosyst Environ. 2009;129(4):542–46. https://doi.org/10.1016/j.agee.2008.10.014
4. Migahid AM, El Shourbagy MN. The ecological amplitude of the desert grass *Panicum turgidum.* 1. Comparison of climatic conditions at Ras El-Hikma, Fuka and Almaza. The Bull Inst Desert. 1961;8(2):1–20.
5. Gul B, Ansari R, Ali H, Adnan MY, Weber DJ, Nielsen BL, et al. The sustainable utilization of saline resources for livestock feed production in arid and semi-arid regions: A model from Pakistan. Emir J Food Agric. 2014;26(12):1032–45. https://doi.org/10.9755/ejfa.v26i12.19102
6. Zuloaga FO, Salariato DL, Scataglini A. Molecular phylogeny of *Panicum* s. str. (Poaceae, Panicoideae, Paniceae) and insights into its biogeography and evolution. PloS One. 2018;13(2):e0191529. https://doi.org/10.1371/journal.pone.0191529
7. Osman AE, Makawi M, Ahmed R. Potential of the indigenous desert grasses of the Arabian Peninsula for forage production in a water-scarce region. Grass Forage Sci. 2008;63(4):495–503. https://doi.org/10.1111/j.1365-2494.2008.00656.x
8. Madouh TA, Al-Sabbagh TA. Innovating forage production system in Kuwait using locally adapted native desert plant species. J Agri Horti Res. 2021;4(1):53–61. https://doi.org/10.33140/jahr.04.01.01
9. Heneidy SZ, Halmy MW. The nutritive value and role of *Panicum turgidum* Forssk. in the arid ecosystems of the Egyptian desert. Acta Bot Croat. 2009;68(1):127–46. https://hrcak.srce.hr/36158
10. Madouh TA. The influence of induced drought stress on germination of *Cenchrus ciliaris* L. and *Cenchrus setigerus* Vahl.: Implications for rangeland restoration in the arid desert environment of Kuwait. Res Ecol. 2023;5(1):1–11. https://doi.org/10.30564/re. v5i1.5426
11. Seema M, Athar H. Germination and growth of *Panicum turgidum* provenance under saline conditions. Pak J Biol Sci. 2003;6(2):164–66. https://doi.org/10.3923/pjbs.2003.164 .166
12. Farag MA, El Fishawy AM, El-Toumy SA, Amer KF, Mansour AM, Taha HE. Antihepatotoxic effect and metabolite profiling of *Panicum turgidum* extract via UPLC-qTOF-MS. Pharmacogn Mag. 2016;12:S446–S453. https://doi.org/10.4103/09 73-1296.191455
13. Heneidy SZ, Waseem M. Rehabilitation of degraded coastal mediterranean rangelands using *Panicum turgidum* Forssk. Acta Bot Croat. 2007;66(2):161–76. https://hrcak.srce.hr/file/26522
14. Almutawa AA. Native and xeric plant recommendations for urban landscapes in Kuwait. Technol Hortic. 2022;2(1):1–16. https://doi.org/10.48130/TIH-2022-0007
15. Bokhari UG, Alyaeesh F, Al-Noori M. Nutritional characteristics of important desert grasses in Saudi Arabia. J Range Manage. 1990;43(3):202–04. https://doi.org/10.2307/3898672
16. ElKhazan M. Response of *Pancium turgidum* plant of habitat variation at the southwestern region of Saudi Arabia. J King Abdulaziz University-Meteorol, Environ and Arid Land Agri Sci. 2007;18(1):3–22. https://doi.org/10.4197/met.18-1.8
17. Assaeed AM, Al-Faifi SA, Migdadi HM, El-Bana MI, Al Qarawi AA, Khan MA. Evaluation of genetic diversity of *Panicum turgidum* Forssk from Saudi Arabia. Saudi J Biol Sci. 2018;25(1):123–29. https://doi.org/10.1016/j.sjbs.2017.04.002
18. Madouh TA, Quoreshi AM. The function of arbuscular mycorrhizal fungi associated with drought stress resistance in native plants of arid desert ecosystems: A review. Diversity. 2023;15(3):391. https://doi.org/10.3390/d15030391
19. Alburae N, Alshamrani R, Mohammed AE. Bioactive silver nanoparticles fabricated using *Lasiurus scindicus* and *Panicum turgidum* seed extracts: Anticancer and antibacterial efficiency. Sci Rep. 2024;14(1):4162. https://doi.org/10.1038/s415 98-024-54449-3
20. El-Desoukey RMA. Phytochemical and antimicrobial activity of *Panicum turgidum* (thummam) as a grazing herb against some animal pathogens. EC Microbiol. 2017;5(1):22–29.
21. Brink M, Belay G. editors. Plant resources of tropical Africa 1. Cereals and pulses. PROTA Foundation, Wageningen, Netherlands / Backhuys Publishers, Leiden, Netherlands / CTA, Wageningen: Netherlands; 2006. p. 298
22. Williams JT. Utilisation and taxonomy of the desert grass *Panicum turgidum*. Econ Bot. 1972;26(1):13–20. https://doi.org/10.1007/bf02862257
23. Batanouny K, Zayed K, Kabiel H. Reproductive ecology of *Panicum turgidum* Forssk. Taeckholmia. 2006;26(1):63–88. https://doi.org/10.21608/taec.2006.12282
24. Madouh TA, Quoreshi AM. Terrestrial habitats and ecosystems of Kuwait. In: Suleiman MK, Shahid SA, editors. Terrestrial environment and ecosystems of Kuwait: assessment and restoration, Cham: Springer Nature Switzerland; 2023b. p. 247–63. https://doi.org/10.1007/978-3-031-46262-7_10
25. Bhatt A, Bhat NR, Al-Nasser A, Carón MM, Santo A. Inter-population variabilities in seed mass and germination of *Panicum turgidum* and *Pennisetum divisum* on the desert of Kuwait. J Arid Land. 2020;12:144–53. https://doi.org/10.1007/s40333-019-00 17-6
26. AbdAllah EF, Tabassum B, Alqarawi A, Alshahrani T, Malik J, Hashem A. Physiological markers mitigate drought stress in *Panicum turgidum* Forssk. by arbuscular mycorrhizal fungi. Pak J Bot. 2019;51(6):2003–11. https://doi.org/10.30848/PJB2019-6(12)
27. Koyro HW, Hussain T, Huchzermeyer B, Khan MA. Photosynthetic and growth responses of a perennial halophytic grass *Panicum turgidum* to increasing NaCl concentrations. Environ Exp Bot. 2013;91:22–29. https://doi.org/10.1016/j.envexpbot. 2013.02.007
28. Aria AK, Asadpour R, Esfahan EZ, Amin M. Ecological characteristics of *Panicum turgidum* in Hormozgan province. J Bio and Env Sci. 2014;5:464–69.
29. Madouh TA. Development and utilization of desert forages for sustainable livestock production under Kuwait conditions (FA078C) [Final Report]. Kuwait Institute for Scientific Res. KISR 11626. Kuwait; 2013
30. Ghannoum O. C4 photosynthesis and water stress. Ann Bot. 2009;103(4):635–44. https://doi.org/10.1093/aob/mcn093

31. Vanaja M, Yadav SK, Archana G, Lakshmi JN, Reddy PR, Vagheera P, et al. Response of C_4 (maize) and C_3 (sunflower) crop plants to drought stress and enhanced carbon dioxide concentration. Plant Soil Environ. 2011;57(5):207–15. https://doi.org/10.17221/346/2010-PSE

32. Jungcurt T. Analyses on the diversity of drought tolerance in grasses of the genus *Panicum.* [Doctoral dissertation]. Universitätsbibliothek Johann Christian Senckenber; 2014

33. Skerman PJ, Riveros F. Tropical grasses. FAO Plant Production and Protection Series; 1990

34. Baltzoi P, Fotia K, Kyrkas D, Nikolaou K, Paraskevopoulou AT, Accogli AR, Karras G. Low water–demand plants for landscaping and agricultural cultivations - A review regarding local species of Epirus/Greece and Apulia/Italy. Agric Agric Sci Procedia. 2015;4:250–60. https://doi.org/10.1016/j.aaspro.2015.03.029

35. Sun H, Kopp K, Kjelgren R. Water-efficient urban landscapes: Integrating different water use categorizations and plant types. HortSci. 2012;47(2):254–63. https://doi.org/10.21273/HORTSCI.47.2.254

36. Kotrade P, Werner A, Ebersberger I, Brüggemann W. Comparative transcriptomics reveal insights into the drought response of the three *Panicum* species *P. bisulcatum, P. laetum* and *P. turgidum*. Plant Gene. 2020;23:100232. https://doi.org/10.1016/j .plgene2020.100232

37. Wouw MV, Jorge MA, Bierwirth J, Hanson J. Characterisation of a collection of perennial *Panicum* species. Trop Grassl. 2008;42 (1):40–53.

38. Bhatt RK, Rajora MP, Kalia RK. Diversity, conservation and uses of pasture grasses of hot arid region of India. In: El-Beltagy A, Saxena MC, Yadav OP, Panwar NR, editors. Proceedings of the 13th International Conference on Development of Dry Lands. Converting Dryland Areas from Grey into Green; 2019 Feb 11-14; Jodhpur, India; 2019. p. 288–90.

39. Abu-hashim M, Omran ESE, Allouche FK, Negm A. Update, conclusions and recommendations for "Agro-environmental sustainability in MENA regions". In: Abu-hashim M, Allouche FK, Negm A, editors. Agro-environmental sustainability in MENA regions, Springer International Publishing; 2021. p. 433–57. https://doi.org/10.1007/978-3-030-78574-1_19

40. Al-Dousari AM, Ahmed MO, Al-Senafy M, Al-Mutairi M. Characteristics of nabkhas in relation to dominant perennial plant species in Kuwait. Kuwait J Sci Eng. 2008;35(1A):129–50.

41. Suzuki N, Rivero RM, Shulaev V, Blumwald E, Mittler R. Abiotic and biotic stress combinations. New Phytol. 2014;203(1):32–43. https://doi.org/10.1111/nph.12797

42. Hameed A, Khan MA. Halophytes: biology and economic potentials. Karachi Univ J Sci. 2011;39(1):40–44.

43. Oatham MP. Water relations of *Zygophyllum hamiense*, *Heliotropium kotschyi* and *Panicum turgidum* and their response to rangeland management techniques in Abu Dhabi. J Arid Environ. 1997;35(1):95–110. https://doi.org/10.1006/jare.1995.0133

44. Roche D. Stomatal conductance is essential for higher yield potential of C3 crops. Crit Rev Plant Sci. 2015;34(4):429–53. https://doi.org/10.1080/07352689.2015.1023677

45. El-Khatib AA, Hegazy AK. Growth and energy content of three forage grasses from the Middle East rangelands. Acta Agron Hung. 2001;49(2):119–31. https://doi.org/10.15 56/aagr.49.2001.2.2

46. Saqib M, Schubert S. Enhancing maize grain yield under salt-affected field conditions using salt-resistant maize hybrids and higher planting density. J Plant Nutr Soil Sci. 2023;186(3):259–65. https://doi.org/10.1002/jpln.202200423

47. Unger PW, Stewart BA, Parr JF, Singh RP. Crop residue management and tillage methods for conserving soil and water in semi-arid regions. Soil Till Res. 1991;20(2-4):219–40. https://doi.org/10.1016/0167-1987(91)90041-u

48. Nield JM, Baas ACW. Investigating parabolic and nebkha dune formation using a cellular automaton modelling approach. Earth Surf Processes Landforms. 2008;33(5):724–40. https://doi.org/10.1002/esp.1571

49. Capstaff NM, Miller AJ. Improving the yield and nutritional quality of forage crops. Front Plant Sci. 2018;9:535. https://doi.org/10.3389/fpls.2018.00535

50. Al-Rowaily SL, Abd-ElGawad AM, Alghanem SM, Al-Taisan WA, El-Amier YA. Nutritional value, mineral composition, secondary metabolites and antioxidant activity of some wild geophyte sedges and grasses. Plants. 2019;8(12):569. https://doi.org/10.3390 /plants8120569

51. Bryant JP, Kuropat PJ. Selection of winter forage by subarctic browsing vertebrates: The role of plant chemistry. Annu Rev Ecol Syst. 1980;11:261–85. https://doi.org/10.1146/annurev.es.11.110180.001401

52. Heneidy SZ. Browsing and nutritive value of the most common range species in Matruh area, a coastal Mediterranean region, Egypt. Ecol Mediterr. 2002;28(2):39–49. https://doi.org/10.3406/ecmed.2002.1572

53. Adams DC, Clark RT, Klopfenstein TJ, Volesky JD. Nutritional value of grazed forages and how it fits the cow's requirement. In: Proceedings of the range beef cow symposium XIV; 1995 Dec 3-6; Gering, Nebraska: USA; 1995

54. Zaki AA, Qiu L, Ali Z, Khan SI, Khan IA. Anti-inflammatory steroidal saponins from *Panicum turgidum*. J Agric Basic Sci. 2016;1(2):1–6.

55. Zaki AA, Ali Z, Wang YH, El-Amier YA, Khan SI, Khan IA. Cytotoxic steroidal saponins from *Panicum turgidum* Forssk. Steroids. 2017;125:14–19. https://doi.org/10. 1016/j.steroids.2017.06.003

56. Zaki AA, Kaddah MM, Abulkhair HS, Ashour A. Unravelling the antifungal and antiprotozoal activities and LC-MS/MS quantification of steroidal saponins isolated from *Panicum turgidum*. RSC Adv. 2022;12(5):2980–91. https://doi.org/10.1039/D1RA08532H

57. Ramteke R, Doneria R, Gendley MK. Antinutritional factors in feed and fodder used for livestock and poultry feeding. Acta Scientific Nutri Health. 2019;3(5):39–48.

58. Onyeonagu CC, Ukwueze CC. Anti-nutrient components of guinea grass (*Panicum maximum*) under different nitrogen fertilizer application rates and cutting management. Afr J Biotechnol. 2012;11(9):2236–40. https://doi.org/10.5897/ajb11.748

59. Egan AR, Ulyatt MJ. Quantitative digestion of fresh herbage by sheep. J Agric Sci. 1980;94(1):47–56. https://doi.org/10.1017/s002185960002788x

60. Chapman DF, Parsons AJ, Cosgrove GP, Barker DJ, Marotti DM, Venning KJ, et al. Impacts of spatial patterns in pasture on animal grazing behavior, intake and performance. Crop Sci. 2007;47 (1):399–415. https://doi.org/10.2135 /cropsci2006.01.0036

61. Bayala J, Ky-Dembele C, Kalinganire A, Olivier A, Nantoumé H. A review of pasture and fodder production and productivity for small ruminants in the Sahel [ICRAF occasional paper no. 21]. World Agroforestry Centre; 2014

62. Helal A. Industrial characteristics of wool produced from sheep fed on salt tolerant fodder crops. J Am Sci. 2013;9:770–77.

63. Masters D, Edwards N, Sillence M, Avery A, Revell D, Friend M, et al. The role of livestock in the management of dryland salinity. Aust J Exp Agric. 2006;46(7):733–41. https://doi.org/10.1071/EA06017

64. Masters DG, Norman HC. Genetic and environmental management of halophytes for improved livestock production. In: Khan MA, Ozturk M, Gul B, Ahmed MZ, editors. Halophytes for food security in dry lands, Academic press; 2016. p. 243–57. https://doi.org/10.1016/B978-0-12-801854-5.00015-7

65. Inam R, Sultan JI, Muhammad Y, Nawaz H, Javed I, Hameed M. Mineral profile, palatability and digestibility of marginal land grasses of Trans-Himalayan grasslands of Pakistan. Pak J Bot. 2008;40(1):237–48.

66. Hajebi A, Soltanipoor MA. Investigating preference index-based palatability of rangeland plants in Sirik Region, Hormozgan Province. Desert Ecosystem Engineer. 2022;11(34):59–70.

67. Edwards NJ, Hebart ML, Craig AD, Abraham EA, Edwards HJE. Applying nitrogen increases pasture and sheep production on puccinellia-based pastures in the SA SGSL experiment [CD-ROM]. In: Ridley A, Feikema P, Bennett S, Rogers M, Wilkinson R, Hirth J, editors. In: Proceedings of the conference salinity solutions: working with science and society CRC for Plant-based management of dryland salinity: Perth; 2004

68. Khan D, Ahmad R. Effects of irrigation with amended dilutions of seawater on germination, growth and cations distribution in *Panicum turgidum* Forsk. A desert fodder graminoid. Int J Biol and Biotech. 2007;4(2-3):149–57.

69. Zaki AA, El-Amier YA, Ashour A. Two new cytotoxic tetralin derivatives from *Panicum turgidum*. Nat Prod Res. 2023;37 (10):1595–600. https://doi.org/10.1080/1478 6419.2022.2103121

70. Guesmi S, Mahjoubi M, Pujic P, Cherif A, Normand P, Sghaier H, Boubakri H. Biotechnological potential of *Kocuria rhizophila* PT10 isolated from roots of *Panicum turgidum*. Int J Environ Sci Technol. 2022;19:10105–18. https://doi.org/10.1007/s13762-021-03824-y

71. Al-Ghanayem AA, Sobeai MS, Alhussaini SM, Joseph B, Saadabi AM. Short communication: Antibacterial activity of certain Saudi Arabian medicinal plants used in folk medicine against different groups of bacteria. Nusant Biosci. 2017;9(4):392–95. https://doi.org/10.13057/nusbiosci/n090409

72. Alam MK, Ahmed S, Anjum S, Akram M, Shah SM, Wariss HM, et al. Evaluation of antipyretic activity of some medicinal plants from Cholistan desert Pakistan. Pak J Pharm Sci. 2016;29(2):529–33.

73. Haddouchi F, Chaouche TM, Halla N. Phytochemical screening, antioxidant activities and hemolytic power of four Saharan plants from Algeria. Phytothérapie. 2018;16:254–62.

74. Mousa W, Alramadan N, Ghemrawi R, Izneid AT. Revealing culturable fungal microbiome communities from the Arabian Peninsula desert representing a unique source of biochemicals for drug discovery and biotechnology. F1000Res. 2024;13:1527. https://doi.org/10.12688/f1000research.158130.1

75. Madouh TA, Davidson MK. Phytochemical screening and potential effects of *Farsetia aegyptia* Turra seeds: A native desert herb, from Kuwait. J Trop Agric. 2024;62(1):81–96. https://jtropag.kau.in/index.php/ojs2/article/view/1428

76. Kernick MD. An assessment of grass succession, utilization and development in the arid zone. In: Chapman GP, editor. Reproductive versatility in the grasses, Cambridge University Press; 1990. p. 154–81

77. Zimmermann T, Bocksberger G, Brüggemann W, Berberich T. Phylogenetic relationship and molecular taxonomy of African grasses of the genus *Panicum* inferred from four chloroplast DNA-barcodes and nuclear gene sequences. J Plant Res. 2013;126:363–71. https://doi.org/10.1007/s10265-012-0538-y

78. Zohary M. Plant life of Palestine, Israel and Jordan. The Ronald Press: New York; 1962

79. Misak R, Omar S, Abdulhadi A. Geomorphology and sustainable management for the sand dunes of Kuwait. In: Sand dunes of the northern hemisphere: distribution, formation, migration and management, CRC Press; 2023. p. 103–28. https://doi.org/10.1201/9781003290629-10

80. Omar SA. Influence of precipitation on vegetation in the rangelands of Kuwait. In: Range management in arid zones. Routledge; 2014. p. 127–38

81. Omar SA. Dynamics of range plants following 10 years of protection in arid rangelands of Kuwait. J Arid Environ. 1991;21:99–111. https://doi.org/10.1016/S0140-1963(18)30732-8

82. Abo-Hassan AA. Rangeland management in Saudi Arabia. Rangelands. 1981;3:51–53.

83. Naghizadeh N, Badripour H, Louhaichi M, Gamoun M, Niamir-Fuller M. Rangelands and pastoralism of the Middle-East and North Africa, from reality to dream. In: Proceedings of Joint XXIV International Grassland and XI International Rangeland Kenya 2021 Virtual Congress; Volume 1, Kenya; 2022. p. 04–08.

84. Kamrani K, Arzani H, Javadi SA, Nejad RA. Rangeland condition and the appropriate rangeland management methods. J Agric Sci. 2019;26(4):524–31. https://doi.org/10.15832 /ankutbd.556745

85. Omar SA, Zaman S. Post-war rangeland status of Kuwait. In: West NE, editor. In: Proceedings of the Fifth International Rangeland Congress, Rangelands in a Sustainable Biosphere; 1995. p. 414–15.

86. Quoreshi AM, Madouh TA. Kuwait deserts and ecosystems in the context of changing climate. In: Suleiman MK, Shahid SA, editors. Terrestrial environment and ecosystems of Kuwait: Assessment and restoration, Cham: Springer Nature Switzerland; 2023. p. 341–59. https://doi.org/10.1007/978-3-031-46262-7_14

87. Clawson M. Developing strategies for rangeland management: A report prepared by the committee on developing strategies for rangeland management, National Research Council, 25. Nat Res J. 1985;260–63.

88. Bullock JM, Aronson J, Newton AC, Pywell RF, Rey-Benayas JM. Restoration of ecosystem services and biodiversity: conflicts and opportunities. Trends Ecol Evol. 2011;26(10):541–49. https://doi.org/10.1016/j.tree.2011.06.011

89. Grealish G, Fitzpatrick RW, Asem SO. Assisting non-soil experts to identify soil types for land management to support restoration of arid rangeland native vegetation in Kuwait. Arid Land Res Manage. 2015;29(3):288–305. https://doi.org/10.1080/15324982.2014.973620

90. Ningappa KR, Kumar S, Singha JP. Role of *Panicum turgidum* dominated rangelands in conservation of *Caralluma edulis* in Thar Desert, India. The XXIII International Grassland Congress; New Delhi, India; 2015.

91. El-Keblawy A, Al-Ansari F, Al-Shamsi N. Impact of dormancy regulating chemicals on salinity induced dormancy in *Lasiurus scindicus* and *Panicum turgidum*: Two desert glycophytic grasses. Plant Growth Regul. 2010;62:163–70. https://doi.org/10.1007/s10725-010-9501-x

92. Quinton DA, Majak W, Hall JW. The effect of cattle grazing on the growth and miserotoxin content of Columbia milkvetch. J Range Manag. 1989;42(5):368–71. https://doi.org/10.2307/3899540

93. Mohamed AH, El-Shesheny MA, Badawy HS. Estimating grazing capacity for desert rangelands of Wadi Hederbah in Southeastern Egypt. Adv Environ Biol. 2019;13(10):22–31. https://doi.org/10.22587/aeb.2019.13.10.3

94. Brown G, Peacock J, Loughland R, Aldrami GA. Coastal and terrestrial ecosystem management requirements in the GCC states. ERWDA Internal Report, UAE; 2003

95. Al-Awadhi JM, Abd el-aal, A ea K, Misak R, Abdulhadi A. Geo-and environmental hazard studies in Kuwait. In: Abd el-aal, A ea K, Al-Awadhi JM, Al-Dousari A, editors. The geology of Kuwait; Springer; 2022. p.171–98. https://doi.org/10.1007/978-3-031-16727-0_8

96. Hadi K. Current status, challenges and future management strategies for water resources of Kuwait. In: Suleiman MK, Shahid SA, editors. Terrestrial environment and ecosystems of Kuwait: Assessment and restoration, Cham: Springer Nature Switzerland; 2023. p.141–69. https://doi.org/10.1007/978-3-031-46262-7_6

97. Al-Shammri ARS, Abahussain AA, Abdalla AAM, Al-Murad MA. Groundwater quality and its suitability for irrigation at Al-Wafra agricultural area in the state of Kuwait. Arab Gulf J Sci Res.

2014;32(4):213–22. https://doi.org/10.51758/agjsr-04-2014-0026

98. Boote KJ, Adesogan AT, Balehegn M, Duncan A, Muir JP, Dubeux Jr JC, Rios EF. Fodder development in sub-Saharan Africa: An introduction. Agron J. 2022;114(1):1–7. https://doi.org/10.1002/agj2.20924
99. Chase LE. Climate change impacts on dairy cattle. Fact sheet, climate change and agriculture: Promoting practical and profitable responses; 2006 Available from https://climateandfarming. org/pdfs/FactSheets/III. 3Cattle. pdf. 2006
100. Guesmi S, Afef N, Petar P, Kais G, Rania O, Marwa J, et al. Roots of the xerophyte *Panicum turgidum* host a cohort of ionizing-radiation-resistant biotechnologically-valuable bacteria. Saudi J Biol Sci. 2022;29(2):1260–68. https://doi.org/10.1016/j.sjbs.2021.09.020
101. Madouh TA, Suleiman MK, Quoreshi AM, Davidson MK. Diversity of arbuscular mycorrhiza fungi in the arid desert ecosystems of Kuwait: Detection and identification from perennial native grass roots. Diversity. 2025;17(2):130. https://doi.org/10.3390/d17020130

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