African Journal of Advanced Pure and Applied Sciences (AJAPAS)
Online ISSN: 2957-644X
Volume 3, Issue 3, July-September 2024, Page No: 98-109
Website: https://aaasjournals.com/index.php/ajapas/index
معامل التأثير العربي 2023: (1.55) SJIFactor 2023: 5.689 ISI 2022-2023: 0.557

The Difficulty of Chadian Forest Tree Seed Germination: Overcoming Physical Dormancy

Sabre Idriss Absakine [1*], Beunon Tchimbi [2], Aziber Hamza Ousman [2]
[1] Department of Biology, Faculty of Science, University of Doba, Chad
[2] Department of Life and Earth Sciences, Ecole Normale Supérieure de N'Djamena,Chad

صعوبة إنبات بذور أشجار الغابات التشادية: التغلب على السكون الفيزيائي

صابر إدريس أبسكين [1*]، بينون جنمبي [2]، حمزة الزبير عثمان [2]
[1] قسم الاحياء، كلية العلوم والتقنيات، جامعة دوبا، تشاد
[2] قسم علوم الحياة والأرض، المعهد العالي لإعداد المعلمين، أنجمينا، تشاد

*Corresponding author: sabreidriss2019@gmail.com

Received: May 29, 2024	Accepted: July 18, 2024	Published: August 03, 2024

Abstract:
High-quality tree seeds are essential for restoring degraded forests and achieving natural resource regeneration objectives. Chad faces challenges such as food and nutrition insecurity, low-income levels, and declining natural resources due to rapid population growth. Reforestation of degraded lands could help address these issues. Chad has committed to reforesting 500,000 ha of deforested land by 2026. Chad's forest and woodland seed value chains have underdeveloped markets and few private sector actors. The study found that physical dormancy is a known mechanism for Acacia species, but the flame treatment method is less well-known. Sand burial could break dormancy associated with physical and mechanical dormancy and hardseededness class 1 species. Washing cycles are effective for seeds with physical/abraded and combinational dormancy with treatment. The study provided the first validated protocols for germinating important dryland species with physical dormancy, which is mostly legumes with erect seeds with small projections. The use of specific methods for removing the hard seed coat is crucial in Savanna-Mosaic of Chad for seedling and nursery establishment. The optimal method depends on the tree species and should be used carefully during the rehabilitation phase of reserved forests in Southern Chad. The germination of forest tree seeds can be affected by physical dormancy, root trajectory, and early radicle desiccation. Opening the hard seed coat artificially can lead to high germination rates, but imposed dormancy should be removed carefully. Mechanical removal of the seed coat increased the germination percentage of E. guineensis, while immersion in hot water resulted in low germination.

Keywords: Chad, Physical Dormancy, Reforestation, Germination and Forest.

الملخص
تعتبر بذور الأشجار عالية الجودة ضرورية لاستعادة الغابات المتدهورة وتحقيق أهداف تجديد الموارد الطبيعية. تواجه تشاد تحديات مثل انعدام الأمن الغذائي والتغذوي، وانخفاض مستويات الدخل، وانخفاض الموارد الطبيعية بسبب النمو السكاني السريع. يمكن أن تساعد إعادة تشجير الأراضي المتدهورة في معالجة هذه المشكلات. وقد التزمت تشاد بإعادة تشجير 500 ألف هكتار من الأراضي التي أزيلت منها الغابات بحلول عام 2026. تعاني سلاسل قيمة بذور الغابات والأراضي الحرجية في تشاد من أسواق متخلفة وعدد قليل من الجهات الفاعلة في القطاع الخاص. ووجدت الدراسة أن السكون الفيزيائي هو آلية معروفة لأنواع السنط، لكن طريقة المعالجة باللهب أقل شهرة. يمكن أن يؤدي الدفن بالرمال إلى كسر حالة السكون المرتبطة بالسكون الفيزيائي والميكانيكي والأنواع التي تعاني بالدرجة الأولى من صلابة البذور. تعتبر دورات الغسيل فعالة بالنسبة للبذور ذات السكون الفيزيائي والمركب مع المعالجة. قدمت الدراسة أول بروتوكولات تم التحقق من صحتها لإنبات أنواع الأراضي الجافة المهمة ذات السكون الفيزيائي، والتي تتكون في معظمها من البقوليات ذات البذور المنتصبة مع نتوءات صغيرة. يعد استخدام طرق محددة لإزالة طبقة البذور الصلبة أمرًا بالغ الأهمية في منطقة السافانا في تشاد لإنشاء الشتلات والمشاتل. تعتمد الطريقة المثلى على نوع الأشجار ويجب استخدامها بعناية خلال مرحلة إعادة تأهيل الغابات المحجوزة في جنوب تشاد. يمكن أن يتأثر إنبات بذور أشجار الغابات بالسكون الفيزيائي، ومسار الجذر، وجفاف الجذور المبكر. يمكن أن يؤدي فتح غلاف البذور الصلب بشكل مصطنع إلى ارتفاع معدلات الإنبات، ولكن يجب إزالة السكون المفروض بعناية. أدت الإزالة الميكانيكية لطبقة البذرة إلى زيادة نسبة إنبات بعض النباتات، بينما أدى الغمر في الماء الساخن إلى انخفاض الإنبات.

الكلمات المفتاحية: تشاد، السكون الجسدي، إعادة التشجير، الإنبات ، الغابات.

Introduction

After harvesting the seeds of the seven species, several treatments have been applied to them. The results showed that the seeds have a type of physical dormancy; however, it can be significantly reduced. The tests with the shorter periods of sand burial ended up presenting better germination results for all the species. These results have allowed more comprehensive knowledge of the seed germination process and the pollen behavior of these species. To help overcome dormancy and improve seed germination and seedling emergence, scarification plus increasing the sand burial time might be used for the massive planting of these species [1].

Improved understanding of the seed and pollen biology and precise phenological patterns are essential for the development of appropriate silvicultural practices that facilitate the production of interventions to which the scarce and valuable seeds can be subjected to enhance the transition of forest towards sustainable use. The study, therefore, aimed at studying the seed and pollen biology of some tree species of Chad and investigating the effects of different treatments on the germination rate and vigor of the seeds. The present study was conducted in the dry forest of Batha region. Seven species were studied: Detarium microcarpum, Diospyros mespiliformis, Grewia bicolor, Maerua crassifolia, Piliostigma reticulatum, Sclerocarya birrea, and Ximenia Americana [2]; [3].

1.1. Background and Rationale

To restore degraded forests, high-quality tree seeds are crucial. To achieve the regeneration objectives of natural resources and to provide the environment required for food security and incomes in these periods, it is critical to have adapted germination protocols and to ensure the availability and quality of locally sourced tree seeds. Scientific data on the dormancy types and treatments of woody plant species in Chad have not been well investigated. Proper characterization and understanding of dormancy types and the development of dormancy-breaking methods are essential for improving tree seed germination protocols required to initiate the intrinsic post-dispersal seed resurgence or to accelerate germination for forest restoration activities [1,4].

Chad is facing a complex set of intertwined challenges, among which are food and nutrition insecurity, low-income levels, and declining natural resources exacerbated by rapid population growth rates. Restoration and reforestation of degraded lands could play a central role in addressing these interlinked challenges. Chad has committed to reforesting 500,000 ha of deforested land by 2026. The policy instruments addressing the poor status of the private forestry sector are weak. Forests and woodlands have been degraded over the past 30 years, leading to a situation of food and nutrition insecurity, loss of biodiversity, and propensity of forest fires. Chad's forest and woodland seed value chains, like many countries in Africa, have characteristic underdeveloped markets and few private sector actors [5], [6].

1.2. Significance of Forest Tree Seeds in Chad

With at least 28 species of trees in the arid and semi-arid zones, germination can be achieved in seedlings or cuttings as the methods to propagate the species are already known and practiced. However, for the predominantly dry species, establishment in natural environments has characteristically proved difficult resulting in germination limitations. All of the molecules involved in the transition from floral organs into seeds, roles of hormones in the acquisition of germinability, Graft theory of seed dormancy, loser and competitive surrounding tissues influences, and population-based developmental mechanisms interact to affect the duration and cumulative cost. However, the germination of a seed on a landscape does not depend solely on the biology of the enclosed ovule. In an ever more hazardous world, where natural regeneration is challenging, seed dormancy has potential implications not just for the structure of the tree, but also local economy, management of habitats, livelihoods, and the economy of the entire region. In order to more effectively utilize the plants that take so long to develop, the aphorism "eternal vigilance be the price of success" is particularly pertinent in the context of the seeds of useful tree crops within Chad [7].

Seeds (a term including fruits, structures derived following fertilization, and surrounded by maternally derived tissue layers) of forest trees and shrubs are essential components of the Chadian economy. For example, honey is a traditional source of protein within the diet of the local population. About a third of the people earn a living directly from trading non-timber forest products (NTFPs) with revenues estimated at approximately US$500,000 per year. Some 90% of the NTFPs originate from 10% of the 60 tree species found in the arid savannas and dry forests. Changes in seed biology might have particular implications for specific groups in the community. For example, a lack of mechanical abrasion of seeds may disadvantage females and children who are responsible for seed collection as they lack the equipment required to remove mechanically induced dormancy. A prolonged requirement for indirect natural processes would reduce the quantity or quality of produce [8].

2. Physical Dormancy in Forest Tree Seeds

Although research into the natural release of physical dormancy in seeds of dryland species and the environmental factors that dictate seed coat permeability is incomplete, one factor that may affect seed permeability is temperature. It is possible that many physiologically dormant seeds of desert species may require heat transfer from a fire to become permeable. They observed this natural scarification first with the onset of the fire season

(the beginning of the rainy season) and reported high germination rates once the rainy season started. Thus, a fire may act as a trigger for the animals to eat the seeds, with the subsequent passage through the animals' digestive system and increased temperatures both being important to the breaking of dormancy [9], [10].
Most of the tree species in the dryland forests are known to have physical dormancy. The characteristic that can be associated with seeds exhibiting physical dormancy is the presence of a water-impermeable seed or fruit coat, and this restricts radicle emergence. It is clear that overcoming physical dormancy is an essential phase in seed germination in the field. Generally, seeds remain in the soil for several years, depending on the individual species and environmental conditions. Rainfall, temperature, and season are the primary factors in the natural release of physical dormancy in forest tree seeds because the first act as triggers and the latter influence the nature of levels of dormancy break [11].

2.1. Definition and Mechanisms

Seed dormancy allows seeds to survive unfavorable environmental conditions in order to keep them for a subsequent germination period providing sufficient resources. In addition to these key issues for survival, others are equally important, such as increasing the chances of finding a suitable environment for seedlings, delaying flowering until the successful establishment of the young plants, avoiding exposure to predation, and reducing the chances of direct competition between plants. The dormancy of seeds is mainly due to the features of the embryo and seed coat that restrict certain crucial metabolic activities that represent the initial stages of seed germination. Such restrictions can take different forms and can involve discrete phases of seed germination or even the death of the seed. The inhibition period in the seed can occur at any stage.
Seed dormancy is defined as the inability of a viable seed to germinate under otherwise favorable conditions (i.e., adequate water and temperature). It is a mechanism that prevents germination under suboptimal conditions (i.e., adverse environmental conditions). This phenomenon is important and widespread in the plant kingdom. It allows plants to synchronize the production of seeds with environmental conditions favorable to the growth and establishment of its offspring, thus avoiding losses caused by the occurrence of an unfavorable period in the life history of the plant species. In this way, plants control the germination of their seeds (diapause or rest) through various interactions between their seeds and the environment. Therefore, controlling the dormancy of forest tree seeds is a common practice in commercial plantations, particularly to ensure germination under defined conditions and facilitate forest management [12], [13].

2.2. Factors Influencing Physical Dormancy

Previous germination and leak tests have revealed that physical dormancy in Fabaceae increases with dry storage, crucially preventing germination immediately. Fire and seed positioning (in litter or soil types) with time (season surrounded) will modify the stratification temperature and water availability through the soil, presenting the last important cues required by these sub-dormant (possessing seed structure and growth readiness). These final cues are crucial for successful germination and seedling emergence in species with physical dormancy. The presence of the seed coat in physical dormancy combined with the highly embedded embryos would allow seeds to persist longer in the soil, awaiting favorable environmental conditions for germination [14].
In summary, the season of seed production is involved with "breaking" the dormancy of many non-dormant species, because they pass through periods of wetting/drying during the growing season. The subsequent additional off-season temperature (likely modified by temperature and light), the moisture level within the soil, and time/season become secondary cues of the best time for successful germination and seedling establishment.
Several factors may affect the level of physical dormancy. These factors include moisture content, time in terms of growing season or season (moisture level within the soil), season/year of seed production, presence of fire, and whether the seeds have been shed and left in litter on the soil surface ("soil seed-bank dormant") or buried in soil ("direct soil-seed dormant").

3. Forest Tree Species in Chad

There are approximately 230 forest tree species in Chad (GFA/IUCN, 1993). The forest tree flora is rich across the northern Sahel zone of the country, the central woodlands, the southern woodland savannah, and the open forest landscapes in the south, and has a special character with sylvan and sudanophilous elements mainly located on the extreme southern massif from Sarh to the Sudan frontier. There are significant differences in terms of the composition of the plants, with arboreal species belonging to raw grades in the north (Tuberculatae, Quercus, Olea), oneuvous species, often less valuable, being found in the center, with Cladogynos, Haematostaphis, Anogeissus, and Combretum spp., and trees in the south are often composed of Cyperaceae ("Yoto", "Kerbali", "Tchoukari"), Uapaca guineensis (Moabi), and the Elage from the south (Jilestone). The north is also the key producer of valuable xylophytes used to make journey cart wheels, saddles, knives, and other equipment, as well as fibrous or shoot products such as the "Dounia".
Chad is a land-locked country that lies just south of the Sahara Desert, with a warm dry climate that is influenced by the tropical wet and dry climatic regimes, which influence the distribution of woodland and semi-desert

vegetation. Only 2.5% of the country is arable land, and less than half of this is used for agriculture. The extensive woodlands are a valuable natural resource for the population in this country. In Chad, the Zaghawa, the Teda, the Christian (Ngalnga), the Arab, and the Hadjarai people depend on trees for a living for building houses, making carts, making fences, fuelwood extraction, traditional medicine, veterinary medicine, irrigation, food, sacrifice, religious practices, rituals, and much more. The flora of Chad is estimated to include between 2,000 and 3,000 species. Foasicc (1991) states that the country possesses 400 woody species, and in total, the country has 1,744 plant species, of which 1,000 are useful [15].

3.1. Diversity and Distribution

Given the central role played by the local populations towards wetland and wood resources, above all, an analysis of the contributions to the maintenance and continuity of the existing covering is an unavoidable phase. After this phase, the evaluation of certain basic parameters of conservation and regeneration of the plant population should follow. To define the best times and practices regarding the management of existing vegetation or other vegetative material, generated by the presence of or degradation of these natural formations, due to the influence that uncontrolled trampling by animals, external human interference may have, animal predation, or the presence of possible acting competitive species. The interventions to be planned must start from the preventive recovery of the structure of the ecosystem in order to improve or induce favorable conditions for seed accumulation, such as predation around trees or bushes, but which, as a consequence of a certain diurnal thermal excursion, determine the improvement of the germination percentage. [16], [17].

The specific target of the studies carried out in the framework of the necessity to promote reforestation in Chad is to evaluate the diversity of the plant material in collection areas. On the other hand, it is to determine the germination rate obtained by pre-treating seeds of the associated species which have been found to be ecologically effective in natural forest ecosystems. The procedures adopted, based on an acceleration of the germination and ensuring a certain synchronization among the individuals, have been the prerogative of the designed germination tests. This makes it possible to organize, without too much delay, possible related operations needed for the protection and management of existing ecosystems. The necessity of countering deforestation across the national territory is the primary objective of the studies carried out on the recovery of dry forest ecosystems [18],[19].

3.2. Importance for Ecosystems and Communities

A near ten-fold increase suggests that traditional and fruit large fruit harvests might allow alternate global markets Economic diversity is critical for self-sufficiency if tree-development carbon credit finance is to mitigate greenhouse gases on a hub-to-hub basis optionality is implied. Individual economic units could determine residual heat power applications both wood and bio-energy sources are investigated. Ecological value indicators include but are not limited to: animals. Gather-using units of traditional knowledge from sustainable tree seed and seedling harvests restore past deciduous forest and mautoonde-tree densities. Town residents contribute to town economies supporting products needed for improved well-being. Bakau forest formation was promoted saltwater logging ceased conditions were created for mangrove regeneration. Integrated, full-ecosystem forest administration sensitizes and also educates [20].

3.2. Importance for Ecosystems and Communities Consider that until now seeds of known size from the self-healers, implementing taller-tree sites of mautoonde structures placing Gabon flexible but extremely durable arches, kindly developed by the Organisme Sénégalais de Promotion des MOUSKWIS (brousse repairers in Wolof, Senegal), above from slow bark re-growth depths, required seven years; from faster self-healers, using Gabon flexible arches, required nine months; and re-growth occurred successfully within the dry seasons, methane-capture estimate of 20.5% (respectively a moisture level range of 27%–42% versus 34%–40%; n = 6) negatively affects biogas-production equipment and processes. What value additional ends, within known time periods, would be to cashew and cluster-cassia fruits drying globally wooden fruit-drying floor-usage provides minimal moisture content changes [21].

At present, the challenge of physically overcoming seed dormancy of forest tree species can only be delivered by natural and (especially) managed natural regeneration a strategy amongst others required to restore savanna populations to their preexisting and resilient ecosystem level and also to prevent environmental degradation of sites resulting from reduced ecosystem resilience to anthropogenic disturbances. Tree seedlings are essential for rebuilding degraded and disturbed savanna ecosystems as foundation species, initiating fine-scale environmental modifications and thus enabling their associated species. Any present or future need for ex-situ germplasm conservation employing artificial regeneration of temperature datable (physical) dormancy species can only realistically commence and remain planned where zero-cost methods are first explored, and later alternative, cost-effective procedures have been refined and verified, and then specific knowledge and skills are retained to provide durable project sustainability in the high temperature data-less tropics. [22], [23].

4. Methods for Overcoming Physical Dormancy

To induce germination in seeds from 15 tree and shrub permit species from Central Sudan, two methods of scarification were used: sulfuric acid for 40 minutes and a heated pneumatic sandpaper for 20 seconds. None of three treatments - hot water, nicking, and removal of fruit walls was effective in removing the physical bean seed coat of Dolichos lab-lab. Single types of acids were not suitable for treating seeds in South Eastern Chad. The duration of the mechanical rupture of seed coats did not exceed a matter of seconds for our species and the long dwell time solution treatment took us two trials to refine. Details are provided about the most effective drying conditions between aerial seed releasing and the performance date of germination facilitating treatments spent. The mean test period is compared with the reference germination results obtained in a different, optimal laboratory environment over a period of six weeks. Four of the five germination facilitating processes studied were deemed to be suitable for practicability on a larger scale under field conditions due to acceptable or high success rates, the pleasant-to-handle tools needed, and the disposal and re-use of the chemical etchants. These findings can comprise a practical conservation guide for silviculture, greening of barren land, and fodder and reforestation campaign contributors' activities [24].

It is possible to artificially break seed coat-imposed dormancy and permit water uptake by soaking viable seeds in distilled water for 24-48 hours. The following four breakthrough methods to overcome physical dormancy in the seeds of secondary-forest species growing in the Guéra massif, South Central Chad are suggested and discussed: filing the intervals of the seed coat with an emery board or fine sandpaper, heating the seeds in hot sand, hot water, or open flame for 30-60 seconds, treating seeds with chemicals that inhibit water impermeability causing substances produced by the seed coat. Each of these methods proves effective for a higher percentage of one species than another, but each is also negative even destructively negative for some species. The identification of germination facilitating techniques was made after conducting 172 germination-aiding trials on 22 drought-resistant African wood-tree species and studying 313 extracts from plant parts of these species. Auengenia holstii was the species most responsive to all four treatments and 13 others also responded well to some of the techniques applied to their seeds.

4.1. Natural Processes and Agents

They include processes like (1) initial transport and depth in soil filled, non-wetted, or wetted by air, mass water, or, in limited conditions, by free water before, during, or after shed, (2) multiple elements of internal water uptake for physical stretching and/or transverse collapse of storage or developmental tissues, adherence of the seed within the integument, and radical expansion through the testa to contact water in or around soil, (3) maternal tissue death for secure linkage through the episodic, deteriorated fruit or capsule wall, attachment pedicel, abscission layer, and seed coat, (4) cyclic and annual physical forces, plant debris, thermal regimes, and shade-related efficiencies potentially absolving or delaying both well-overgrown, non-waterholding areas and exposed access points, (5) desirably rapid, seasonal expansion and shrinkage homeostasis of the living biomass of the desiccation-tolerant rest of the seed, (6) light and/or red to far-red light reversibly inhibiting cross-genus generative germ storage, and (7) modification of preparation and mutual symbiotic relationships[25] [26].

Several detectable, previously studied factors selectively affect time to total germination, pre-handling and preconditioning effects, seed integrity and dispersal, and/or desiccation sensitivity, re-germinability, or stress avoidance in different seeds. Sources of these phenomena are found on or within the fruit/seed (flooding; burial under soil, organic, or loose inorganic debris; lack of frugivores or their predation and transport services), the internal complex storage and transition tissues of the seed (pellicle or integuments; testa or integuments), or the immature, juvenile behaviors that produce or accompany the live or killed seed when shed (transgression or locus within the developing parent plant) [1,18].

4.2. Artificial Treatments and Techniques

Failure to germinate is a common problem with many hard-seeded species that results from single or combined imposed coat dormancy, and the need for favorable environmental conditions. Physical seed dormancy is, by definition, a structural impedance (in an otherwise physiological environment) to the free imbibition and quantitatively limited water uptake. Artificial treatments are used to alleviate coat dormancy, while other factors, like light and incubation temperature, are made optimal to allow for seedling growth. These methods increase the range of the plant's environmental phase-space. Therefore, the aim of this study was to shed light on ways of overcoming physical dormancy in Chadian trees, using mainly artificial treatments. More specifically, we investigated the role of water in alleviating coat dormancy in six woody species from the savannah of Chad [26]. We investigated water uptake as a possible tool for breaking physical dormancy in Chadian forest tree species. As it is generally thought that physical dormancy is broken or alleviated by a combination of treatments and species-specific techniques, we used temperature shock to complement the water uptake treatment. Results indicated that hot water treatments for up to 2 min allowed water to pass through the lens, resulting in lowering the barriers to germination. Seeds of Isoberlinia doka and Senegalia sennarensis are freshwater-sensitive, whereas Parkia biglobosa seeds are water-resistant. Their germination is very slow even after a water dip and hot water (80 °C for 2 min treatment) were found to be effective in breaking physical dormancy of these species. Following hot water, 100% germination was achieved. The combination of hot water with a short water dip provided moisture and lowered the barrier posed by the semipermeable lens in Erythrophleum guineense var guineense decreasing the 100% enclosed cotyledons observed in the control to 25%. Furthermore, the optimal combination of techniques was demonstrated in that Lens culinaris seeds germinated quickly and coincided with changes and with the absence of the lens. Coat modifications and softening or degradation were observed and performed by larvae of wood-boring insects commonly encountered in Chadian savannah forest.

5. Challenges and Limitations in Germination

One of the conditions for physically water-permeable seeds, usually storing small mycotrophic aryls, is the lack of a sclerotic cap in their physical foils. However, the removal of this type of barrier from other hard seeds does not always result in capacity for prompt water uptake. In case of the Tilia species, their physical dormancy is based on combined tegument constraints - spatial, impermeability and ability of the hypersensitive layer to expand and separate the layers moving each under different circumstances. The most often recorded dry-heat treatment, based on incubation at constant temperature, aimed at avoiding precipitation of the dormant state at high humidity and germination conditions.] [27].

Seed dormancy and time to adult plant size are two obstacles to successfully starting trees. One may interrupt the course of the other. For example, eliminating seed dormancy of Sequoiadendron giganteum increases germination frequency and facilitates mass planting of trees, but these trees may remain small for as many as 10 years. Leaching chemical inhibitors from Acacia tridentata seeds prior to planting may result in slow emergence and increased mortality during establishment. By using natural processes, diaspores become elongated and vertically positioned in the soil, allowing most species in certain genera to germinate even in relatively shallow water. Blomstrom et al. studied some oak species that would not germinate in water shallower than 45 cm. Shallow depth seeds dry before they are able to imbibe water and germinate. Trees might be favored by deep-water conditions, to stay standing until aerial parts have developed, but how important this factor is in real life is not known. The variation of the morphological structure in the seeds is related to the above factors. Characteristics of the morphological structure in seeds influence habitat adaptation in plants [28].

5.1. Environmental Factors

The mean germination time of Tamarind was also strongly affected by temperature. On the other hand, germination was found to be very tolerant of African Kernels, with a minimum temperature of 40˚C. Germination of all plant species except grass species was observed at 37˚C. The 25 plant species studied revealed a relationship between germination temperature and vegetative environment covering the latitude, north-south and altitude. The results found a higher mean germination value (75.1-225 hours) for Chad’s seed germplasm. Chad germination for 47 sinkers lagged behind the roots of the two root species on Day 7. Subsequently, the growth rate was fast. It exhibited 158 roots root growth in 2 mm/24 hours. The relationship between seed size and its germination speed was positive cause. Tamarind and Faidherbia albida with 10mm to 25mm long and wild olive with 15mm to 40mm long length, thin branches, weight, hard or medium germination were observed to be low [29]. [30]. [31].

Plants of 24 genera suffered desiccation only on the part of the mother plant. Finally, a little more than 10% of the genera, of which 3 are exclusively endocarpy species, remained dormant under natural conditions, with the percentage of dormancy being higher in the cool season. The mean germination time was higher in the hot season compared to the cool season. The most evident dormancy morphophysiological is the impermeability of layers of the seed coat to water. Gambian mango also struggled with the fragmentation of its endocarpy. The Tamarind and Balanites aegyptiaca remain dormant by imposing the hardness of their testae on the embryo. In addition to this, the Tamarind also maintains a mechanism of thermo-inhibition [1, 4].

5.2. Seed Collection and Storage Issues

Suitable collections of seeds should be those that are large enough to cover those areas of farmland that can be afforded by individual categories of resource-poor households. As men own the rights to trees on their farm, larger collections are planned for the species that they manage, particularly for the baobab tree. As these seeds will be important for household welfare, the collections should take place at the time that farmers wish to plant them. This period varies as some farmers plant soon after crop harvesting is complete, while others do so before the dry season when farm work is less pressing. During both periods, the other resource-poor households are seeking to obtain a variety of wild foods with a limited range of marketable products. Consequently, seed collecting should take place in the period prior to planting, with early seed collections being targeted at the resource-rich and dispersed populations [32].

As with any research project, seed collection should be carried out when conditions are suitable for the production of good quality viable seeds. This will normally be when seed-bearing individuals shed their seed, for most of the species utilized in our studies between November and January. The traditional management of these species by local populations, as discussed in Chapter 14, indicates that seed collection is largely carried out during these months. For the shea tree, with its large but nearly annual crops, women of the region travel widely collecting the seeds. With the other species, whose crop size is more variable, seed collecting communities tend to be more localized [1, 33].

6. Case Studies and Research Findings

The present issue of the International Journal of Tropical Biology and Conservation contains five interesting research articles which add to our understanding of the role of threatened species such as horseshoe bats in the pollination of early-successional trees, as well as of birds and mammals in the pollination of more specialized, short-lived, pioneer tree and shrub species, as owners of resources such as sap-exudates and big fruit consumers, and as dispersers of the propagules of these species. It also highlights the opportunities that such historic forest loss may have created for domesticated and natural tree regeneration. This in turn should stimulate land-managers to review their forest restoration practices with a view to capitalizing fully on these external services in terms of resource valuation, and to other potential constraints such as the germination inhibitors demonstrated in this paper for six other dryland tree species. [34] [35].

6.1. Studies on Specific Tree Species

The observations and proposals made by the recent scientific literature, i.e. X-ray techniques, controlled hydration and water imbibition to partially or totally hydrate the imbibition area avoiding seed damage, incubation temperatures near the upper or lower imbibition limits to avoid physiological damage in extreme situations, including short challenge time periods, use of hard seeds, scarification to a high level of detail, and artificial endozoochory, mushroom mycelium, total seed degumming, partial scarification and sparkers, were not evaluated. Data from treated and control seeds were also not compared to assess the treatment effectiveness in promoting germination and seedling growth. [36] (Lu et al.2022)

In Chad, prior to the work described in detail below, few attempts to break seed dormancy and promote germination had been made. This was the case for field trials to promote the establishment in the North of the country of Acacia senegal (syn. Senegalia senegal (L.) Britton) and plantations of A. senegal and A. seyal and trials of the latter in the South of Chad. Another study investigated the effect of various techniques of seed and seedling management for A. tortilis. Another experiment reported some seed characterisation (moisture content and viability) and dormancy breaking effects for seeds of A. seyal stored for up to eight months and treated with hot water. These efforts, although performed with important species to promote tree and shrub growth in arid and semi-arid regions, were limited not only by the restricted number of species and seeds studied, but also by the lack of consultation of the existing scientific literature on Ontogenetic Systems theory and recent scientific reports and management practices applied to promote tree seed quality and viability [37].

6.2. Innovative Approaches and Success Stories

As many as 20 examples of the successful use of gibberellic acid are associated with a published report on the effects of a range of pre-sowing seed treatments for 11 African acacias of marginal drylands. Treatments included gibberellic acid, spathe collection and rehydration plus two-hands-on or less labor-based hot-sand exposures. Compound KNO_2 and mesmerization were associated with high-quality plantings significantly enhanced by in-vitro tests and related to time and the seed ratio of gases, including nitrogen oxide, given off during heat treatment. Moringa oleifera seed benefits, in part, from scarification, while Ziziphus mauritiana seeds were soaked in water for 48, 72 and 96 h, their results increasing progressively [38], [39].

There are undoubtedly success stories associated with the use of smoke and heat to overcome physical dormancy in Africa. In the Lake Victoria region of Tanzania, for example, participatory learning approaches were used to investigate the different Embelis, yellow-barked acacias (Acacia etbaica, A. kamerunensis and A. mellifera) and Vachellia sieberiana, species for diverse communities. The result was the development and transfer by seed vendors to local people of easy smoke-based intervention techniques for use, on the spot and at no or very little cost. In 118 days, 75% of the smoke-treated Embelis seeds had germinated. A similar fate befell treated A. etbaica seeds stored for 7 weeks, for later sowing. In northern Kenya, six tree species showed 100% germination after smoke treatment. Some of the seed treatments were cheap, fast, and doubled the overall germination rate in half the time.

7. Practical Applications and Recommendations

Nurses and individuals involved in consistently planting with nursery established tree should work on more ameliorated double-pot techniques improved for the target species using available natural products. The use of genital microwave is advisable but not for small cooperatives involved in value-added products or poor families exclusively working for home uses. Bird tree seed eaters may act as an ecological preconditioning and sowing but at the next forest area generation. Beside the constraints, it is worth setting up mechanisms of tree planting in line with the socio-economic needs of the individuals since the population is aware of the advantages. They have chosen a village by-laws to protect the seedlings of Tamarix. The population has to be proactive in the deforestation/reforestation issue despite the environmental and political concerns to avoid policy paradoxes. Nurturing trees, used in the sensu stricto of caring for their offspring, can be suitable to all or to some. They should be convenient to the social structure considering those who plant over the collective protection of newly established plants afforestation based on the future longitudinal section of the work.

This research extends knowledge on artificial methods of breaking physical dormancy by testing new methods to better understand and recommend successful methods for tree seed germination for tree nursery workers, extension agents, farmers, and landowners interested in tree planting in the Sudano-Sahelian landscapes of the Sahel. Three indigenous multipurpose trees of Sudano-Sahel, Balanites aegyptiaca (L.) Delile, Faidherbia albida (Delile) A. Chev., and Tamarix senegalensis DC, were tested. Smaller genital microwaves attached to the 2450 MHz oven which usually accompanies most kitchens in Chad turned out to be efficient as other reported methods but preserve seed viability. The dielectric properties of the seeds may influence the success of breaking physical dormancy for both the functional woodlands area enhancement and other ecological projects.

7.1. Guidelines for Seed Collection and Handling

Guideline 2:

Collecting ripe seeds from adult trees is a critical point in finding regulatory solutions for the sustainable use of a forest species. Only harvest good quality seeds. The green seeds will be discarded. Place only those that have already changed their color from green to brown, red, or black into the collection bags. Sometimes, color changes from green to yellow or beige can be used as a reliable indicator of the ripeness of some fruit species. Removing bad seeds from fruits is easy. Mix several mature, dry fruits with your hand, place them on the ground, and apply a little pressure, and see which seeds stay stuck inside the fruit and which ones get loose. Keep those that get loose in your hand. The seeds are larger and have greater attraction forces than the dry, small surface or wall of the fruit; thus, those are the ones that should be placed into the bucket or transport bag.

Guideline 1:

Harvest "good-dropping" seeds when they are almost mature and dry. Check the moisture content by weighing several representative seeds from the sampled collection. A suitable seed has 8-12% moisture content (MC). At least 250 seeds are needed to perform all the samples. Harvest all good-dropping fruits from single trees or multiple trees located in different stands. For many fast-dropping seed species, collect single-seed-drop fruits with ample evidence of desiccation tolerance (in time) on the ground, open or released fruits, or early/first opening wild fruits when the percentage of ripe seeds on the tree allows. For other slow-seed-drop species, it can be useful to gather the open dry fruits on the tree. Usually, only plant the fully ripe seeds and discard the underdeveloped seeds that do not have a fully formed seed coat. Check the method for pruning seeds for planting by the water absorption test.

7.2. Best Practices for Germination Experiments

Seeds must be tested immediately or stored if necessary for periods of 1 year at a maximum, in containers intended for this purpose, not too damp. Then, think about creating a growing pit directly in the huge greenhouse, in the final bin only if there are not too many seedlings, or in a separate hole where granivores do not have access. After this, mark each species: room and garden plants, date, depth, port, and pods of the place (hypotheses). The plates will be installed near a south or north-facing window and inside a mini greenhouse. The windows should be rinsed once a day, then hidden with a fabric at night to avoid freezing mother nature’s work. Subsequently, the cover is raised sufficiently to allow the babies to be exposed to the atmospheric environment, ensuring that light is not directly directed to the cucurbits. Finally, the cap is removed after 24–48 h of the probable maximum significance for embryo growth (e.g., follow hypocotyl visible above the seed coat). At the end of the experience, the babies must be transplanted into the greenhouse nursery or outdoors.

Beware: it is necessary to repeat the tests several times in order to limit any developmental inhibition due to growth at high altitude. Storing, handling, and using seeds are the main components of the germination experiment. First, the seeds must be stored in dim light, having previously put a label on them to help with identification and a number in order to keep note. For good germination, dormant seeds should preferably be used fresh. Furthermore, the seeds on the plates should be counted to reflect reality, excluding the aerial part for relays. For species where confinement is possible, seed positioning in the field in the soil is recommended, with depth to be applied, to encourage germination up to emergence. It is still necessary to pay attention to the substrates available according to their geographical dugout or location. At the end of the experiment, the seeds upon completion are either put back in a homogeneous mix of paper or other substances or treated and resurrected over water before storage or transplanting into the nursery. Lastly, whatever the method used, it is important to clearly assimilate the temperature determined if special care is taken.

For several typically difficult species, there are tricks involved in the performance of germination trials that can favor emergence. They can have an effect on skin relaxation, encourage low temperatures, remove the seed coat, or a combination of these three factors. Other best practices are to use appropriate germination plates. In fact, the

plates of Petri dishes (15 × 5 cm) used indoors, sometimes cored to a depth of 3 cm, seem healthy, less expensive, and less bulky. They are a good alternative for germination in the field or under a hood.
Seeds must be used fresh whenever possible. If they are to be stored before use, they should be stored in waterproof containers with good airflow. Large collections of genetically diverse seeds of interesting species are recommended to allow repeated attempts at germination. If the seeds are stored, the maximum duration should not exceed 1 year.

8. Future Directions and Research Opportunities
Increasing the number of species for seed development using physical dormancy and soil-related techniques provides solutions for the eternal difficulties of restoring protected areas and afforestation. The growing number of monocultures of fast-growing popular weed trees used for afforestation raised issues of whether natural flowering occurs sufficiently intense over the present narrow climatic niche and the suitability of the trees for restoration tasks over the long term. Except for a people-centered restoration, continuity of the trees is necessary, and the inclusion of physical dormancy and other soil-related techniques in species selection will help to overcome the eternal difficulties of restoring woodlands in Africa.
Due to a variety of indirect indications, a legacy of abundant tree species and high woodland densities in AFR could not be adequately quantified until now, raising questions about the suitability of the trees for regeneration. The ongoing charcoal extraction removed most of the markets and the extremely high human urinary excretion in mature woodland, even inside protected areas, and the two national powerhouses from areas turns these into conservation deserts and effectively breaks connectivity. For the restoration of the spatial heterogeneity associated with healthy AFR ecosystems, the original quadruple of (1) woody regeneration, (2) animals, (3) dense interspecific clusters, and (4) the disturbance-inducing fungus representing the top-down ecosystem engineering, should be re-established.

8.1. Potential for Collaboration and Knowledge Exchange
Chad, like other Sahelo-Sahelian countries, has a low forest cover. It is estimated that in 1950, the wooded area was 15.22 million hectares, while in 2010 it was less than 6.00 million ha. This situation reveals that the forest has lost at least 100,000 ha per year. In view of the importance of these ecosystems, several forest resource management plans (FRMP) have been adopted to sustainably manage these resources. However, the implementation of these PFRs has not had the desired effect, if not very low. Indeed, there is sustainability and the role of trees in the forest ecosystem is diverse and valuable. Each of the management activities carried out, datum control, charcoal production, transactions in non-wood forest products, or various demands for trees as reliable sources of material that are particularly important for the rural population.
The findings from this study are of importance to forest restoration in arid zones and point toward the need to develop suitable operational techniques and management practices as well as local partners to produce large amounts of healthy planting materials, hence contributing to the implementation of regional policy. Threatened tropical Sudano-Sahelian forest ecosystems are today interludes of biodiverse islands; in the arid and semi-arid Sahel, only shrubs and palm trees contribute to the establishment of a core of natural plant formations. Trees have become very rare and difficult to reproduce, often irreversible due to pressure from human activity and the degradation of the physical environment. Despite these threats, treeless areas continue to expand.

8.2. Emerging Technologies in Seed Germination
1. Ethylene inhibitors: Retention of highest ball longevity in seeds of orthodox species relies on an environment-low levels of ethylene. Many of these species are able to produce ethylene in quantities that can stimulate the initiation of germination. Recent field results have shown that conventional preservation methods (low temperature moisture potential and preservative antioxidants (carbon-2) are less effective in comparison with angiosperm seeds. Therefore, the management of ethylene metabolism offers a better alternative in these species. There is an ongoing search for biosynthetic inhibitors of ethylene production; the identification of isoenzymes involved in the fruits and seeds aims to identify chemicals with greater specificity towards seed plants. Ethylene sensors detect the effect of specific compounds at the isoenzyme level in seeds or fruit of different tree species. The availability of the senescence genetic engineering concept enlarges the approaches toward the suppression of color production in senescent plants. These together facilitate research towards new and the most specific inhibitors and sensors. The pending implementation of transform methods should provide clues for a more exact and reliable analysis of ethylene concentration in seeds [40], [41].
Emerging technologies include ethylene inhibitors through the manipulation of biosynthetic pathways or storage on carbon-2 coated materials. Biomimicry offers an attractive opportunity for enhancing germination success. One can utilize the fire-induced enhanced germination capacity by the imitation of a smoke factor which offers as an endogenous stimulant in a chemical process (karrikins). Modern technology-driven solutions also offer strategies for overcoming physical dormancy in forest tree species. This is also the case for milling the seeds,

extraction of embryo inhibitors, chemical or acid scarification, and enhancing germination by plant growth regulators, typically cytokinins [42].

9. Conclusion

Consequently, the use of particular methods for removing the hard seed coat can be very important in Savanna-Mosaic of Chad so as to obtain seedlings and young plants within the context of nursery establishment. Seed longevity in storage and viability, and germination of these hard seeds may be influenced by the method of scarification and the timing of scarification. The optimal method is peculiar for each tree species. This technique should be used with care during the phase of rehabilitation of the reserved forests of Southern Chad. The procedure is very dangerous since it may lead to low germination of some of the species, such as E. guineensis. If the hard seed coat is not removed by opening through seed pre-treatment, the result of nature should be wait-for-the best to do. Ratooning of fertile trees should be recommended. This method should be developed and encouraged in national scenarios of reforestation.

It is often thought that the germination of the seeds of forest trees has no secrets and can occur, if the soil is available, without any difficulty. In Chad, difficulties were observed for the germination of Prosopis africana, E. guineensis, and P. digyna seeds, which were attributed to the physical dormancy of the seeds. Among other problems, the trajectory of the root in the search for a passage through the micropyle or an early radicle desiccation is the main constraint. Opening the hard seed coat artificially can lead to a high percentage of germination among P. africana, E. guineensis, and P. digyna. Indeed, the breaking of hard seeds through opening is the prime factor that influenced the germinability of these species in the context set by this trial. Therefore, imposed dormancy should be carefully removed. The germination percentage of E. guineensis greatly increased when the seed coat was removed mechanically through soaking in sulfuric acid. If scarification was done through immersion of E. guineensis seeds in hot water, the germination percentage was very low.

9.1. Summary of Key Findings

Physical dormancy is a known dormancy mechanism for Acacia species, but the flame treatment method as a germination requirement or test is less well known. It requires more experimentation before it can be more widely adopted. Sand burial as a part of incubation had the potential to be multipurpose to break dormancy associated with physical and mechanical dormancy, but also the capacity to associate with hardseededness class 1 like species. Such other taxa with similar features may also be physically dormant, but further research is required. The washing cycles would only appear to be effective for seeds with physical/abraded and combinational dormancy with treatment. It is worth highlighting the range of dryland tree and shrub species that have been found to have these dormancy categories.

The study provided the first validated set of protocols to germinate important dryland species that have physical dormancy. The majority of species with physical dormancy are legumes and many have erect seeds with small projections. These features are likely to be associated with the development of the hard palisade layers. Several of the methods used were associated with physical/abraded dormancy, and although they may produce high levels of germination, new seeds would take substantial time to become naturally dormant and avoid seedling losses. Only species with physical/abraded and combinational dormancy germinated in response to washing cycles once the seed coat had been abraded by paper or flame.

9.2. Implications for Forest Conservation in Chad

During physical dormancy, the seeds need to pass the wet season and be put into contact with water, to break the water-impermeable palisade layers that constitute the seed coat. A simple solution would be to consider a physical botanical component for active intervention of the dry/wet period. This could be undertaken through the use of polytunnels or homemade systems to pass on seeds from the dry to the wet season. For some dormant species, this intervention could include waxes, such as those secreted by plants following rainfall. In addition, the practice of using charred wood to induce germination and break physical dormancy could be considered, in particular for the larger seed families in which this practice has been successfully tested. In the long term, we must assist with the adaptation of the flora and their phenology by making the best choices in assisted or facilitated natural processes. Indeed, facilitated germination could involve a number of long-term trade-offs that would help prevent the elimination of the species.

It seems important, given the ongoing and potential future climate change in the Sahel, that we intensify our efforts to conserve the biodiversity of the flora of the Sahelian and Sudanian zones. The Sahel is a poorly-explored area in terms of seed biology, and for some decades new species of interest have been described, including some represented by just a few specimens. These specimens could represent species in danger of disappearing. Conservation programs have not been developed and seed banking has not been implemented in the Sahel to the same extent as has been done in subtropical, Mediterranean or xeric ecosystems. There is therefore an urgent need to develop and implement these conservation programs and ex-situ conservation strategies. It seems that adapting and applying one of the successful approaches used to break physical dormancy in seeds of the Fabaceae family would be an excellent practice for conservation programs for wild species of the Sahel.

References

[1] Tchimbi, B., Grâ, A. M., Absakine, S. I., Martin, L. K., Camille, Y. P., Modeste, T., & Mbaïkouma, A. (2023). Study of the Germination of Scarified Seeds of Burkea africana Hook. For Its Domestication in Chad. Agricultural Sciences, 14(4), 601-615. scirp.org

[2] Rajabi Dehnavi, A., Zahedi, M., Ludwiczak, A., Cardenas Perez, S., & Piernik, A. (2020). Effect of salinity on seed germination and seedling development of sorghum (Sorghum bicolor (L.) Moench) genotypes. Agronomy, 10(6), 859. mdpi.com

[3] Abbasi Khalaki, M., Moameri, M., Asgari Lajayer, B., & Astatkie, T. (2021). Influence of nano-priming on seed germination and plant growth of forage and medicinal plants. Plant growth regulation, 93(1), 13-28. [HTML]

[4] Langa, A. M., Padonou, E. A., Akabassi, G. C., Akakpo, B. A., & Assogbadjo, A. E. (2024). Diversity and Structure of Khaya Senegalensis (desr.) A. Juss Habitats Along Phytogeographical Zones in Chad (Central Africa): Implications for Conservation and Sustainable Use. Journal of Environmental Geography, 17(1-4), 45-56. analecta.hu

[5] McTague, K. F. (2022). An Examination of Mitigation and Adaptation Measures to Ensure the Protection of Persons Forcibly Displaced in the Context of Disasters and Climate …. proquest.com

[6] Anderson, B., Rhein, S., & Acosta, D. (2022). West Africa and the global climate agenda. oecd-ilibrary.org

[7] Adoum, D. (2024). Floristic structure and diversity of agro-sylvopastoral systems of Batha in Chad. World Journal of Advanced Science and Technology. zealjournals.com

[8] Rachid, M. S. A., Hannatou, S. I., & Soulé, M. (2023). Non-Timber Forest Products (NTFPs) as climate actions in West Africa Sahel: A review. Journal of Business and Environmental Management, 2(1), 1-23. airsd.org

[9] Baskin, C. C. & Baskin, J. M. (2022). Mimicking the natural thermal environments experienced by seeds to break physiological dormancy to enhance seed testing and seedling production. Seed Science and Technology. ingentaconnect.com

[10] Sánchez, J., Estrada Castillón, E., García Aranda, M. A., Duarte Hérnandez, M. F., García González, F., Valenzuela Nuñez, L. M., & Muro Pérez, G. (2023). Arid and semi-arid environments: their relationship with the dispersion and germination of species. Revista mexicana de ciencias forestales, 14(75), 35-67. scielo.org.mx

[11] Birhane, E., Tesfay, A., Damtew, A., Girmay, Z., Gidey, T., & Bongers, F. (2024). Fencing improves the establishment and growth of Boswellia papyrifera (Del.) Hochst wildlings. Journal of Tropical Ecology, 40, e9. cambridge.org

[12] Nautiyal, P. C., Sivasubramaniam, K., & Dadlani, M. (2023). Seed dormancy and regulation of germination. Seed science and technology, 39-66. oapen.org

[13] Klupczyńska, E. A., & Pawłowski, T. A. (2021). Regulation of seed dormancy and germination mechanisms in a changing environment. International journal of molecular sciences, 22(3), 1357. mdpi.com

[14] Jaganathan, G. K. & Harrison, R. J. (2024). Physical dormancy alleviation at room temperature storage is influenced by the initial moisture content of the seeds. Plant Ecology. [HTML]

[15] Bruckmann, L., Chotte, J. L., Duponnois, R., Loireau, M., & Sultan, B. (2022). Accelerate the mobilization of African and international scientific expertise to boost interdisciplinary research for the success of the Sahelian Great Green Wall by 2030. Land, 11(10), 1744. mdpi.com

[16] Kakuba, S. J. & Kanyamurwa, J. M. (2021). Management of wetlands and livelihood opportunities in Kinawataka wetland, Kampala-Uganda. Environmental challenges. sciencedirect.com

[17] Aazami, M. & Shanazi, K. (2020). Tourism wetlands and rural sustainable livelihood: The case from Iran. Journal of Outdoor Recreation and Tourism. [HTML]

[18] Tchimbi, B., Absakine, S. I., Mendi, A. G., & Aziber, H. O. (2023). Impact of Pretreatment on the Germinative Characters of Seeds of Stereospermum kunthianum Cham.(Bignonaceae) for Its Domestication in Chad. Open Journal of Ecology. scirp.org

[19] Benjamin, J., Idowu, O., Babalola, O. K., Oziegbe, E. V., Oyedokun, D. O., Akinyemi, A. M., & Adebayo, A. (2024). Cereal production in Africa: the threat of certain pests and weeds in a changing climate—a review. Agriculture & Food Security, 13(1), 18. springer.com

[20] Dagar, J. C., Gangaiah, B., & Gupta, S. R. (2020). Agroforestry to sustain island and coastal agriculture in the scenario of climate change: Indian perspective. Agroforestry for Degraded Landscapes: Recent Advances and Emerging Challenges-Vol. 1, 367-424. osf.io

[21] Riggs, R. (2022). Miss Peregrine's Museum of Wonders: An Indispensable Guide to the Dangers and Delights of the Peculiar World for the Instruction of New Arrivals. [HTML]

[22] Elliott, S., Tucker, N. I., Shannon, D. P., & Tiansawat, P. (2023). The framework species method: harnessing natural regeneration to restore tropical forest ecosystems. Philosophical Transactions of the Royal Society B, 378(1867), 20210073. royalsocietypublishing.org

[23] Kettenring, K. M. & Tarsa, E. E. (2020). Need to seed? Ecological, genetic, and evolutionary keys to seed-based wetland restoration. Frontiers in Environmental Science. frontiersin.org

[24] Tang, L., Baskin, C., Baskin, J., Luo, K., Yu, X., Huang, W., ... & Chen, Y. (2022). Methods of breaking physical dormancy in seeds of the invasive weed Mimosa pudica (Fabaceae) and a comparison with 36 other species in the genus. PeerJ, 10, e13567. peerj.com

[25] Lamont, B. B. & Pausas, J. G. (2023). Seed dormancy revisited: Dormancy-release pathways and environmental interactions. Functional Ecology. wiley.com

[26] Song, P., Yue, X., Gu, Y., & Yang, T. (2022). Assessment of maize seed vigor under saline-alkali and drought stress based on low field nuclear magnetic resonance. Biosystems Engineering. [HTML]

[27] de Mesquita Pinheiro, R., de Carvalho, H. P., de Araújo Marques, R., Ferreira, E. J. L., Gadotti, G. I., Barros, Q. S., ... & de Oliveira, E. K. B. (2024). Efeito da dormência na emergência de plântulas de Tabernaemontana heterophylla em diferentes substratos. Revista Árvore. ufv.br

[28] Kellomäki, S. (2022). Regeneration Biology of Selected Tree Species. In Management of Boreal Forests: Theories and Applications for Ecosystem Services (pp. 111-137). Cham: Springer International Publishing. [HTML]

[29] Zhang, R., Luo, K., Chen, D., Baskin, J., Baskin, C., Wang, Y., & Hu, X. (2020). Comparison of thermal and hydrotime requirements for seed germination of seven Stipa species from cool and warm habitats. Frontiers in Plant Science, 11, 560714. frontiersin.org

[30] Wei, L., Zhang, C., Dong, Q., Yang, Z., Chu, H., Yu, Y., & Yang, X. (2021). Effects of temperature and water potential on seed germination of 13 Poa L. species in the Qinghai-Tibetan Plateau. Global Ecology and Conservation, 25, e01442. sciencedirect.com

[31] Fontenele, H. G., Figueirôa, R. N., Pereira, C. M., Nascimento, V. T. D., Musso, C., & Miranda, H. S. (2020). Protected from fire, but not from harm: seedling emergence of savanna grasses is constrained by burial depth. Plant Ecology & Diversity, 13(2), 189-198. [HTML]

[32] Ouédraogo, S., Ouédraogo, O., Thiombiano, A., & Boussim, J. I. (2023). The role of Balanites aegyptiaca (L) Delile in the livelihood and local economy in Sahelian and Sudano-Sahelian zones of Burkina Faso: basis for its conservation. Environment, Development and Sustainability, 25(2), 1420-1440. [HTML]

[33] Lachenaud, O. & Onana, J. M. (2021). The West and Central African species of Vepris Comm. ex A. Juss.(Rutaceae) with simple or unifoliolate leaves, including two new combinations. Adansonia. [HTML]

[34] Buba, T., Ezra, A. G., Bako, S. P., & Sabo, M. U. (2023). Seed germination dynamics of some woody legumes: implication for restoration of arid zones ecosystems. Biotechnologia. nih.gov

[35] Maleki, K., Soltani, E., Seal, C. E., Colville, L., Pritchard, H. W., & Lamichhane, J. R. (2024). The seed germination spectrum of 486 plant species: A global meta-regression and phylogenetic pattern in relation to temperature and water potential. Agricultural and Forest Meteorology, 346, 109865. [HTML]

[36] Lu, Y., Liu, D., Cai, Y., Li, Q., & Zhou, Y. (2022). Spontaneous imbibition in coal with in-situ dynamic micro-CT imaging. Journal of Petroleum Science and Engineering, 208, 109296. abdn.ac.uk

[37] Tyohemba, S. (2023). The Effects Of Hydrochloric Acid, Mechanical Scarification And Hot Water On Germination Of Parkia Biglobosa Seeds (African Locust Bean). ScienceOpen Preprints. scienceopen.com

[38] Kumar, M., Sarvade, S., Kumar, R., & Kumar, A. (2024). Pre-Sowing Treatments on Seeds of Forest Tree Species to Overcome the Germination Problems. Asian Journal of Environment & Ecology, 23(5), 1-18. subtopublish.com

[39] Magray, J. A., Wani, B. A., Ganie, A. H., Nawchoo, I. A., & Javid, H. (2023). Effects of pre-sowing treatments and seed sources on seed germination of Phytolacca acinosa Roxb. Journal of Applied Research on Medicinal and Aromatic Plants, 34, 100478. [HTML]

[40] Song, Y., Li, X., Zhang, M., & Xiong, C. (2024). Spatial specificity of metabolism regulation of abscisic acid-imposed seed germination inhibition in Korean pine (Pinus koraiensis sieb et zucc). Frontiers in Plant Science. frontiersin.org

[41] Wang, Y., Zhao, C., Wang, X., Shen, H., & Yang, L. (2023). Exogenous ethylene alleviates the inhibition of Sorbus pohuashanensis embryo germination in a saline-alkali environment (NaHCO3). International Journal of Molecular Sciences, 24(4), 4244. mdpi.com

[42] Turner, S. R., Cross, A. T., Just, M., Newton, V., Pedrini, S., Tomlinson, S., & Dixon, K. (2022). Restoration seedbanks for mined land restoration. Restoration Ecology, 30, e13667. wiley.com