Ecology, Socioeconomics, Ethnobotany, Seed’s dormancy and the Mazri Palm {*Nannorrhops ritchieana* (Griff.) Aitch.}; an appraisal from Khyber-Pakhtunkhwa Pakistan

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Department of Plant Sciences
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2024

Ecology, Socioeconomics, Ethnobotany, Seed's dormancy and the Mazri Palm {*Nannorrhops ritchieana* (Griff.) Aitch.}; an appraisal from Khyber-Pakhtunkhwa Pakistan

A thesis Submitted to the Department of Plant Sciences in the partial fulfillment of the requirement for the degree of Doctor of Philosophy in Plant Sciences

By

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2024

Certificate of Approval

This is to certify that the research work presented in this thesis, entitled "**Ecology, Socioeconomics, Ethnobotany, Seed's dormancy and the Mazri Palm {*Nannorrhops ritchieana* (Griff.) Aitch.}; an appraisal from Khyber-Pakhtunkhwa Pakistan**" was conducted by **Mr. Abdullah** under the supervision of Associate Professor **Dr. Shujaul Mulk Khan.** No part of this thesis has been submitted anywhere else for any other degree. This thesis is submitted as a partial fulfillment of the requirement for the degree of Doctor of Philosophy in the field of **Plant Sciences/Botany** to the Department of Plant Sciences, Quaid-i-Azam University Islamabad Pakistan.

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This thesis is dedicated to the esteemed memories of my grandmother and to the myriad of humans around the globe who tragically died during the outbreak of COVID-19.

List of Abbreviations

Abbreviation	Full Form
BTAP	Billion Tree Afforestation Project
Ca	Calcium
CA	Cluster Analysis
CCA	Canonical Corresponding Analysis
CPEC	China-Pakistan Economic Corridor
EWMZ	Eastern wet mountain zone
EC	Electrical conductivity
DFO	Divisional Forest Officer
FATA	Federally Administered Tribal Areas
Fe	Iron
GLM	Generalized Linear Model
GLM	Generalized Linear Model
GPS	Geographical positioning system
GA3	Gibberellic acid
HEC	Higher Education Commission
ISA	Indicator Species Analysis
IUCN	International Union for Conservation of Nature
IV	Importance Value
IVI	Importance Value Index
IAA	Indole acetic acid
Mg	Magnesium
PATA	Provincially Administered Tribal Areas
T_Maxim,	Maximum temperature
MASL	Meter above sea level
T_Minim,	Minimum temperature
NDMZ	Northern dry mountain zone
K	Potassium
Precipit	Precipitation
Rel_Hum	Relative humidity
SAC	Species Area Curve
Spe_Hum	Specific Humidity
SD	Standard deviation
SDFO	Sub Divisional Forest Officer
SPMZ	Sulaiman Piedmont zone
Sso_wet	Surface soil wetness
Tem	Temperature
TDS	Total dissolved solids
WDMZ	Western dry mountain zone
Ws	Wind speed
WSp_Max	Wind speed maximum

Publications arising to date from this Dissertation

The following papers, abstracts and posters have been published from this thesis:

Research Articles:

(1) Abdullah, Shujaul Mulk Khan, Andrea Pieroni, Zahoor ul Haq, and Zeeshan Ahmad. 2020. Mazri (*Nannorrhops ritchiana* (Griff) Aitch.): a remarkable source of manufacturing traditional handicrafts, goods and utensils in Pakistan. *Journal of Ethnobiology and Ethnomedicine*, 16 (2020): 45. https://doi.org/10.1186/s13002-020-00394-0

(2) Abdullah, Zahoor Ul Haq and Shujaul Mulk Khan. 2019. The indispensable bond between Mazri Palm (*Nannorrhops ritchiana*) and the Indian Porcupine (*Hystrix indica*) leads them towards extinction!. *Biodiversity and Conservation*, 28, 3387–3388 (2019). https://doi.org/10.1007/s10531-019-01823-7

(3) Abdullah, Shujaul Mulk Khan, Sara Shehzadi, Yaseen Khan, Majid Iqbal, Shahab Ali, Shakil Ahmad Zeb and Zahoor Ul Haq. 2021. Overcoming seed dormancy in the Mazri Palm; a sustainable way for its production at business scale; MDSRC - 2021, 30 Nov – 01 Dec 2021 Wah/Pakistan.

(4) Abdullah, Shujaul Mulk Khan, Shakil Ahmad Zeb, Shahab Ali, Zahoor Ul Haq and Henrik Balslev. 2024. On the Trail of the Mazri Palm (*Nannorrhops ritchieana*) in Pakistan, PALMS.Vol. 68(1).

(5) Abdullah, Shujaul Mulk Khan, Shakil Ahmad Zeb, Shahab Ali, Zahoor Ul Haq, Dost Muhammad and Henrik Balslev. 2024. Senescence affects fecundity but not germination in *Nannorrhops ritchieana. Accepted in Plant Species Biology, Wiley.*

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(5) Abdullah, Shujaul Mulk Khan, Zahoor Ul Haq, Shakil Ahmad Zeb and Shahab Ali. *2022. Edapho-climatic factors drive intraspecific variation in Nannorrhops ritchieana (Griff) Aitch functional traits in the Hindu-Himalaya* **submitted to** the Join Meeting of Ecological Society of America and Canadian Society for Ecology and Evolution (ESA & CSEE) Joint Meeting ESA) 2022, Under ID No= Abstract ID: 1230726. https://www.eventscribe.net/2022/ESA/fsPopup.asp?PresentationID=1105526&query=Nannorrhops&Mode=presInfo

(6) Abdullah, Shujaul Mulk Khan, Zahoor Ul Haq and Shakil Ahmad Zeb. *2021, Nannorrhops ritchieana* (Griff.) Aitch and its associated flora in the Hindukush range of Northwest Pakistan: An economic Palm. Submitted to the Annual Meeting Vital Connections in Ecology of Ecological Society of America (ESA) 2021, Under ID No=29373.

(7) Abdullah, Shujaul Mulk Khan, Zahoor Ul Haq and Shakil Ahmad Zeb. 2020. Mazri Palm and its associated vegetation in the Tribal regions of Pakistan, International Symposium on *"Plant Life of South Asia (on the successful completion of Flora of Pakistan Project"* at the University of Karachi. February 24 – 27, 2020.

(8) Shujaul Mulk Khan, Abdullah, Muhammad Asif and Hussain Shah. 2019. Mazri (*Nannorrhops ritchieana* (Griff) Aitch. a remarkable source of manufacturing traditional handicrafts, goods and utensils in Pakistan. Proceedings (Supplementary Issue of Pharmacology Online Journal V. December 30) 28th SILAE Congress "International Exhibition for Natural Products Innovation the natural trade meets at the Natural 2019" (September 16 – 20, 2019) at La Habana, Cuba.

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ABSTRACT

The palm family (Arecaceae) is economically and ecologically idiosyncratic. Their pantropical distribution, variation in life forms, and species richness (>2,500 species) make them excellent model organisms for the study of nature. A few species have been recorded from the warm-temperate regions and among them *Nannorrhops ritchieana* is a noteworthy example. It is distributed in different regions of Pakistan, Afghanistan, Oman, Iran, and Saudi Arabia and provides a multitude of ecosystem services. The dramatic increase in the human population causes a severe decline in *Nannorrhops ritchieana* populations by unmanaged harvesting. The consequences of these intimidations on different aspects of this important iconic palm merit active research. The overarching aim of this thesis was to document the *Nannorrhops ritchieana* multifold ecosystem services, socioeconomic importance, population ecology, and associations with other plant species and to overcome its seed dormancy and enhance germination with a long-term management plan. We integrated the study across different climatic zones of Khyber Pakhtunkhwa including (i) Eastern wet mountains (ii) Northern dry mountains (iii) Western dry mountains and (iv) Sulaiman Piedmont. The data regarding ecosystem services and socioeconomic importance was gathered through questionnaires and surveys and resulted in a detailed compilation of 39 different handicrafts with their economic values. The hierarchical clusters of a heatmap identified variations in usages in different areas inhabited by diverse societies. We found that in some areas, the species is intensively harvested which leads to the extinction of its populations. For population ecology, we gathered information from 63 different regions and analyzed the data to understand species density, natality, mortality age structure and fruiting ecology. We assessed 2269 individuals in which the number of seedlings was less than the number of juvenile, young, and mature individuals. The low number of seedlings demonstrates that it will be difficult for seedlings to cover the gap between larger individuals that have already died and others that are facing the problem of death due to multiple abiotic and biotic factors. Road construction, uprooting by porcupines and black bears, fire regimes, agricultural land expansion and invasive species encroachment and plantation in the native habitats of *Nannorrhops ritchieana* are the menaces that lead to mortality. Interestingly, with the increase in height, inflorescence size, fruit number, and fruit and seed size reach their maximum in middle-aged palms, followed by young and then decreases in older plants. These variations in fruit ecology might be related to their nutrient acquisition capacity.

Nannorrhops ritchieana is a gregarious and keystone species that provide habitat and shelter to many other species. We documented 251 species in four major associations (each climatic zone was considered an association). In each association, plots were lumped together using cluster dendrograms and then three indicators, one tree, a shrub and an herb were identified using the indicator species analysis function in PCORD software. We found that the associated vegetation changed from subtropical scrub forests in Sulaiman Piedmont to subtropical pine forests in the Eastern wet mountains with an increase in elevation and precipitation. A canonical correspondence analysis (CCA) plot was created for all species in relation to environmental gradients. We examined the homology in associated species among the four associations using Venn diagrams and the Jvenn online application. *Nannorrhops ritchieana*, being a gregarious species, prefers to live in diverse sorts of associations under the influence of different environmental drivers.

Conservation of *Nannorrhops ritchieana* is one substantial step in its seed dormancy mitigation. Different experimentations on seed dormancy using H2SO4, HNO3, Thiourea, Hot water, GA3 and IAA in different concentrations and immersion times were carried out in the Botanical Garden, Quaid-i-Azam University, Islamabad, Pakistan. We observed that an increase in acids and thiourea concentration damaged the embryo and triggered seed germination for a long-time immersion. Moreover, GA3 and IAA lead to significant germination by providing strength to the embryo. The best non-laborious and inexpensive method is the hot water treatment for 5–15 days at 35–45^{o}C temperature. In addition, we observed that in April, May, June, and July a maximum number of seeds germinated which might be due to the hot temperature causing cracks in the seed coat, through which water easily penetrated inside and caused germination. The result presented in this thesis should be decisive for the sustainable utilization, conservation, management and restoration of *Nannorrhops ritchieana* across its geographic range.

CHAPTER 1

INTRODUCTION

1.1 ECOLOGY OF PALMS

Ecologists, biogeographers and naturalists have been intrigued for centuries by the diversity of plants and animals, distribution and spatial patterns (Lomolino *et al*., 2010). Plant diversity and distribution are significantly influenced by climate (Currie *et al*., 2004), topography, dispersal mechanisms (Svenning *et al*., 2008), photoperiod, habitat heterogeneity and many other biotic and abiotic factors (Kissling *et al*., 2007). Regardless of the comprehensive work, it remains a great challenge and dilemma to know what determines the dynamics and distribution of plants (Pennisi, 2005), especially that of palms. The palm family (Arecaceae) among plants due to its pantropical distribution, variation in life forms, and richness of > 2,500 species make them excellent model organisms for the study of nature (Dransfield *et al*., 2008; Bjorholm *et al*., 2006; Svenning *et al*., 2008; Muscarella *et al*., 2020). They epitomize the tropics, and many species are considered of key importance for the stability and multifold services rendered by the ecosystem. Several animal species depend on their fruits and flowers for their survival (Onstein *et al*., 2017) since time immemorial. Rich fossil records (Harley, 2006) show that they were pioneer monocotyledons on the earth (Janssen and Bremer, 2004). They are divided into five subfamilies and show an astonishing geographic variation in composition, richness, life form and phylogeny (Govaerts and Dransfield, 2005). These variations are due to various factors such as climate, hydrology, soil chemistry, and topography that determine diversity, composition richness and distribution of palms across special scales (Tomlinson, 2006; Svenning *et al*., 2008).

1.2 UNIQUENESS OF PALMS

Palms have a wide ecological distribution across different ecosystems such as lakes and rivers, mangroves, tropical mountains, seasonally inundated forests, tropical rain forests, tropical dry forests, savannahs and desert oases (Tomlinson, 2006). Several palm species represent morphological extremes within the flowering plants. (1) This applies to *Jubaea chilensis* (Molina) Baill which has the widest stem among palms and reached more than a meter in diameter and is built by primary growth (Tomlinson, 1990). (2) *Raphia regalis* Becc., is the palm species with the longest pinnate leaf of 25.11m (Halle, 1977), while

Corypha umbraculifera L. is champion with a palmately compound leaf of 8m blade size and a petiole of five meters in length. (3) The rattan genus *Calamus* has record-long climbing stems that can reach more than 200 meters, more than double the height of the orthodox tallest trees (Burkill, 1966). (4) The *Corypha umbraculifera* has the world's largest inflorescence in the plant kingdom with more than eight meters in length (Blatter, 1926). According to an estimation this long inflorescence holds 23.9 million flowers (Fisher, Saunders & Edmonson, 1987). (5) Double coconut *Lodoicea maldivica* produces record-heavy seeds weighing as much as 25 Kg. How the seeds of this palm propagate and migrate uphill is still a mystery (Tomlinson, 2006). These organisms store more water in their cells and hence they have a great potential for adaptation to a new habitat when they are (large palm trees especially from nurseries) moved after root pruning (Tomlinson, 2006).

1.3 CLIMATE AND PALMS

The Palm family is mainly distributed across tropical and subtropical climatic regions and only a few species have been recorded from the warm-temperate climatic areas (Dransfield *et al*., 2008). Restriction of the Palm family to the tropical and subtropical regions could be linked to limitations that low temperatures pose for photosynthesis and growth (Gatti *et al*., 2008). Palms are temperature sensitive due to their soft and water-rich trunks, their incapability to undergo dormancy and their lack of strategies and mechanisms to circumvent, tolerate or adapt to frost-related stress all of which make them restricted to mega thermal climates (Tomlinson, 2006). Low temperature has been considered a limiting factor in the extreme northern ranges of the family (Walther *et al*., 2007). According to Tripp and Dextor (2006) palms are excellent predictors and indicators of present-day climatic catastrophes based on their temperature sensitivity, expansion and propagation to the extreme distribution boundaries of the family. Palms mostly prefer humid climates except for a few species of the genus *Hyphaene* (Blach-Overgaard *et al*., 2010). Therefore, water is considered in various macroecological studies as an important and key determinant of palm species richness and distribution (Bjorholm *et al*., 2005; Kreft *et al*., 2006). However, substantial variation can occur in climatic conditions at smaller scales, particularly in mountainous regions (Svenning *et al*., 2009; Eiserhardt *et al*., 2011).

1.4 PALMS AND SOIL GRADIENTS

Soil has a crucial role in the distribution, diversity and abundance of palms. The most important ones are soil pore space, bulk density, and soil hydraulic conductivity (Palm *et al*., 2007). At a regional scale, the abundance and distribution of different palm species are linked to physical soil properties but also the content of nutrients (Svenning *et al*., 2001). Barot and Gignoux (2003) demonstrated how soil nutrients drive local distribution patterns in the African palms *Borassus aethiopum*. In tropical regions of South America, palms are generally associated with soil rich in aluminium and clay. In the western Amazon, however, most palms occur on nutrient-rich soil (Ruokolainen and Vormisto, 2000; Camara-Leret *et al.*, 2017). In South Asia, *Nannorrhops ritchieana* which is the subject of this thesis was listed as a plant species that absorbs the maximum amount of Magnesium (Naseem *et al*., 2005).

According to Eiserhardt *et al*. (2011), species turnover observed in the western Amazon may be driven by different nutrient gradients in the soil. Poulsen *et al* (2006) more specifically linked the turnover in a western Amazonian palm community biogeochemical with soil characteristics such as aluminium contents and exchangeable cations. At the regional and continental scales palm species richness may also correlate with palm diversity (Bjorholm *et al*., 2006). Soil biogeochemistry, however, is controlled by other ecological drivers such as hydrology, topography, climate, as well as vegetation structure and composition.

1.5 PALMS AND WATER

In the riverine forest in the Amazon, tall palms respond differently in their growth and survival patterns to local inundation. Prevention of leaf buds and leaves from becoming submerged under water is an important elusion strategy (Garssen *et al*., 2015; Trujillo *et al*., 2021). Several authors have assessed the distribution and abundance of different palm species concerning flooding regimes (Henderson *et al*., 1995). Flooding has an impact on both germination and seedling survival (Pacheco, 2001). Interestingly, the South American species *Oenocarpus bataua* and *Iriartea deltoidea* and *Socratea exorrhiza* have different hydrological preferences throughout their distributional range. Species of *Phoenix* in Africa and Southeast Asia occur mostly in arid and semi-arid regions. They are typically phreatophytes with a well-developed root system that is in contact with the groundwater. Some species are even used as indicators of shallow water tables (Tishehzan *et al*., 2016).

In the case of *Nannorrhops ritchieana* Browse (1993) noted that locally rare in areas where the water table is shallow and available to plants.

1.6 DISPERSAL OF PALMS

In plant species that reproduce sexually seeds, fruits, infructescences or the entire plant may constitute the dispersal unit. Most of these are distributed in interaction with animals. Most often the interaction is mutualistic. Frugivory is a very common seed dispersal mechanism in tropical regions (Fleming *et al*., 1987). By consuming fleshy fruits frugivorous animals often contribute to seed dispersal (Fleming and Kress, 2013; Kissling *et al*., 2009). The Palm family mostly produces fruits of large size in comparison to other plant families. Palm fruits are mostly fleshy and nutritive and hence considered a vital source of food for frugivorous animals (Onstien *et al*., 2017; Munoz *et al*., 2018). A variety of frugivorous animals are involved in the seed dispersal of palms i.e., bats, non-flying mammals, birds, reptiles, insects, and fish (Zona and Henderson, 1989; Munoz *et al*., 2019). In South America species of rodents classified in the genera *Myoprocta* and *Dasyprocta* are involved in the dispersal of *Astrocaryum chambira* palm. They hoard palm fruits to eat them later, during periods of food scarcity (Smythe, 1989). Successful germination occurs when the rodents fail to retrieve the buried fruit (Jansen and Forget, 2001).

Several bird species have inextricable links with different palm species i.e., the Macaw parrot is involved in the propagation of Macaw palm seed (Baños-Villalba *et al*., 2017). *Euterpe oleracea* palm dispersion occurs by *Rupicola rupicola* (bird), *Mazama americana* (mammal), *Myleus rhomboidalis* (fish). *Syagrus oleracea* palm seeds are propagated by the reptile *Tupinambis merianae* (Castro & Galetti, 2004); *Syagrus petraea* (Mart.) Becc. seeds by the mammal *Chrysocyon brachyurus* (Motta-Junior and Martins, 2002) and *Orania sylvicola* seeds by the bat *Pteropus vampyrus*.Cocos nucifera and the invasive palm species *Nypa fruiticans* are dispersed by water.

1.7 LANDSCAPE AND PALMS

Landscape or topographic structure plays a vital role in palm distribution by affecting various other factors such as wind pressure, light duration and frequency, hydrology, and soil conditions, etc. In dry regions of the Amazonian forests palm species richness decreases with elevation (Salm *et al*., 2007). In contrast, Poulsen *et al*., (2006) recorded the highest richness in palm species with elevation in terra Firme forests of the Amazon. In northwestern Pakistan Abdullah (2019) observed increasing numbers of *Nannorrhops* *ritchieana* individuals with increasing elevation but with a concomitant decrease in plant length, leaf width and length. Landscape variation is associated with variation in floristic differentiation as documented in several studies of palms (Vormisto *et al*., 2004; Kahn, 1987; Costa *et al*., 2009; Svenning *et al*., 2008).

1.8 ETHNOBOTANY AND SOCIOECONOMICS

Traditional knowledge is established by rural and indigenous communities through long-time practices and experiences of adapting to their surrounding (Paniagua-Zambrana et al., 2014). It is a crucial and key component in a region improving peoples' livelihoods (Reyes-García et al., 2008), natural resources management and conservation (Huntington, 2000; Shackeroff and Campbell, 2007). Traditional knowledge is dynamic and continuously modified, but very little attention has focused on understanding the changes resulting from adaptations to new environmental, cultural, social, and economic conditions (Gómez-Baggethun and Reyes-García, 2013). Such changes may lead to the loss of local knowledge systems (Benz et al. 2000, Brosi et al. 2007), which could result in a reduced ability to cope with environmental changes.

Over the past two decades, many studies have sought to understand how social, economic, cultural, environmental, and geographical factors influence traditional knowledge about plants at small scales. Factors such as gender, age, ethnicity, birthplace, and level of education have been identified as important on an individual level (Byg and Balslev, 2006, Paniagua Zambrana et al., 2007). Although many of these studies might reflect the specific relationship that each culture has with natural resources, without a unifying theory or common research method we cannot discern whether such findings reflect patterns and behaviors that are similar, or even identical, between different cultures and broader scales (Alburquerque and Medeiros, 2012). Several studies have used meta-analyses to analyze large-scale usage patterns of plants (Moerman et al., 1999; Molares and Ladio, 2009; Saslis-Lagoudakis et al., 2011), although comparisons are difficult to make, given the diversity of the objectives and methods employed. Evidence of these patterns can serve in generating strategies for the preservation of traditional knowledge at regional scales, without neglecting the characteristics of each region and the dynamic nature of knowledge. If levels of traditional knowledge can be predicted from socioeconomic data, conservation actions could focus better on the population sectors that have more knowledge and are facing greater risks of loss. To compare the influence of these factors on the knowledge of multiple cultures at community and individual levels, research needs to be designed very carefully to allow the elucidation of common patterns (Alburquerque and Medeiros, 2012).

1.9 ETHNOBOTANY AND SOCIOECONOMICS OF *NANNORRHOPS RITCHIEANA*

In this study, we examine the influence of socioeconomic variables on cultural uses and economic benefits using a standardized interview protocol. Specifically, we evaluate the predictive power of three socioeconomic factors previously identified as being important in determining knowledge differences at the personal level (gender, age, and education). We gathered data on different items produced from *Nannorrhops ritchieana* palm because of their extraordinary importance in the livelihoods of indigenous and nonindigenous populations in the region. To our knowledge, this is the first attempt to test the influence of socioeconomic factors on traditional knowledge about a keystone palm species in Khyber-Pakhtunkhwa across different cultural groups. *Nannorrhops ritchieana* is an economic palm species with a significant contribution to the local economy. It is an important source of natural fibers and is used in the production of different utensils, goods, and handicrafts. Various types of mats, baskets, hotpots, salt pots, trays, brooms, hats, grain bins, cordages, hand fans, and various other household commodities. These products are an important source of income across various regions and markets. Jhandai and Lund Khuar Mardan, Billitang Kohat, Takhti Nusrati, Teeri and Banda Daud Shah Karak, Anbar Mohmand, Sadda Kurram, Shahu Oakzai, Khar Bajaur, Paniala D I Khan, Totakan, Batkhela Malakand, Tall, Doaba Hangu are the important markets of Khyber-Pakhtunkhwa. On the other hand, Qasoor, Kot Addu, D G Khan, Bahawalpur and Rawalpindi in Punjab while Loralai, Khuzdar, Musakhail, Quetta, Harnai, Barkan and Mekran in Baluchistan are the districts where *Nannorrhops ritchieana* products are sold in different markets.

About 65,000 people are directly or indirectly involved in the processing of *Nannorrhops ritchieana* leaves, among which 78% are women (Iqbal et al., 1991), The women are doing most of the work starting from harvesting to the finished product. Men and women, with the help of a sickle, harvest the *Nannorrhops ritchieana* foliage from the growing areas. Both fresh and dried leaves are used for product making. One leaf yield about 30 to 40 pieces and five Kg of leaves produce about four Kg of products with a waste of 20% (Latif et al., 2005). The average annual production of raw *Nannorrhops ritchieana* leaves in the country is 37,315 tons in 1991-1992 (Iqbal et al., 1991). Baluchistan is the biggest producer of *Nannorrhops ritchieana* in Pakistan with an average annual production of 27,265 tons.

It has been estimated that on average a *Nannorrhops ritchieana* worker can process more than 0.5 tons of raw *Nannorrhops ritchieana* leaves per year (Iqbal et al., 1993). *Nannorrhops ritchieana* leaves are distributed to various parts of the country through railways and trucks. Palms are not only of cultural importance, but it is also of religious importance and mentioned in religious books and scripts like Holy Quran.

Table 1.1 Vernacular/ Local names of *Nannorrhops ritchiana*

Vernacular or Common names	**Used by Ethnic groups**	**Origin of Languages**	**Citation from previous literature**
Ghadaf, or Saʿf,	Omani in coastal areas	Arabic	(Mosti *et al*., 2006)
Mazri Palm	British	English	(Gibbons, 1995)
Peesh	Sindhi	Sindhi	
Merez	Afghani	Afghani Pashto	(Sabet, 1994)
Patha	Pashto	Loralai	(Ajaib *et al*., 2013)
Mazri	D.I. Khan	Saraiki	(Marwat *et al*., 2011)
Purk	Iranian	Persian	(Khodashenas *et al*., 2016)
Daz	Balochi	Kirthar,	(Panhwar and Abro, 2007)
Mezaray	Pashto	Malakand, Swat, Dir, Bajaur, Mardan	(Murad *et al*., 2011)
Mazri	Urdu	Pakistani	(Adnan *et al*., 2014)
Mazara	Pashto	FR Bannu	(Adnan *et al*., 2014)
Mazarai	Pashto	South waziristan	(Aziz *et al*., 2016)
Mazzari	Pashto	Hangu	(Khan *et al*., 2014)

1.10 THE HOLY QURAN AND PALMS

Palm trees hold a sacred place in the literature of the Holy Quran. They are defined as trees having sheaths. The palm species being monocots do not have a true stem. Their stem comprised of sheaths is almighty Allah revealed in the Holy Quran.

فِيهَا فَاكِهَةٌ وَالنَّخْلُ ذَاتُ الْأَكْمَامِ

“There in is fruit and palm trees having sheaths” (Chapter: 55:68).

The Holy Quran enlightens the structural composition of Palm stems because they are crucial to their stem support and transportation. According to Tomlinson (2006), the sheathing fibers are an important part of the parenchyma cells in the ground tissue and vascular system of the palm stem. They hold metabolic activities in the palm stem throughout their life span.

1.11 THE HOLY QURAN AND PALMS GERMINATION

The palms family is peculiar in germination, seed structure and seedling morphology. A considerable number of palm species due to irregular and very prolonged duration of germination rely only on sexual propagation. Palm species with low germination levels are common and different types of dormancy are documented. Therefore, Almighty Allah addressed in the holy Quran revealed with these words.

إن الله فالق الحب والنوى

"Indeed, Allah is the cleaver of grain and date seeds."

Slow and irregular germination is an adaptive strategy of plants to cope with stress under dry environmental conditions. The Palm family is the leading family facing problems in seed germination.

1.12 HISTORICAL BACKGROUND OF SEED GERMINATION IN PALMS

At the end of the 16th century, Pliny and Theophrastus compiled the first illustration of a palm seedling (Camerarius, 1588). Scientific studies on the germination of palms started at the start of the nineteenth century. The distinction between remote and adjacent seed germination was first proposed by Martius (1823-1850). His work is considered a base for modern seed science. Three types of seed germination based on the attachment of cotyledonary sheath were recognized by Micheels (1889). A very comprehensive review of palm germination based on the early scientific studies of Theophrastus and Pliny contributed by Gatin (1906). The morphological detail of 24 palm species germination and seedlings is given by Zurawska in 1912Ahistorical review of the leaf and haustorium in *Elaeis guinenesis presented by Yam-polsky in 1922*. Seedlings in monocots including a few palm species studied by Boyd in 1932. A series of studies on the germination and seedling of palms is carried out by Ginieis in 1950. Germination pattern of economic palm species explored by Saakov in 1954. The legendary palm biologist Tomlinson (1960, 1990), worked on the germination and seedlings of palm species also drawing their proper illustration. Moor and Uhl (1973) attempted to derive phylogeny from germination traits. Extensive work on the phylogeny of palms by studying 84 palm species belonging to 82 genera was done by Low in 1976. Uhl and Dransfield (1987), disentangled germination type and eophyl shape for various genera of palm. Seedling morphology in all classes of monocotyledons and its importance with seedling traits in their systematics is studied by Tillich in 1995. A comprehensive review of the morphology and anatomy of palm seedlings is published by Henderson (2006). Moreover, many researchers presented various schemes for the classification of seed dormancy most worthy and notable of Harper (1957, 1977), and Nikolaeva (1969, 1977, 2001). Several schemes for classifying seed dormancy have been published, most notably those of Harper (1957, 1977), Nikolaeva (1969, 1977, 2001), Nikolaeva *et al*. (1985), Lang *et al* (1985, 1987), Baskin and Baskin (2004, 2014).

1.13 SEED DORMANCY

The seed is the basic and important entity for reproduction and propagation. It is a storage organ for plant embryos to which it provides food and other essential nutrients. After the dispersal from the parent plant seeds scatter into a variety of habitats of which only a few may be suitable and safe. There is a great possibility for seeds that remain viable for a long time. Their survival chances increase when they ultimately find a more suitable place for themselves. Seed dormancy is a phenomenon in which seeds are unable to germinate in the specified period under any combination of normal physical environmental factors, e.g., light, dark, water, or temperature (Baskin and Baskin, 2004). Seed dormancy has been classified into three classes based on their emergence such as enforced, innate, and induced (Harper 1977). On the other hand, Baskin and Baskin, (2004) explained three other types of seed dormancy i.e., deep, intermediate, and non-deep. Seeds with deep dormancy from excised embryos lead to abnormal seedling production. Germination cannot occur in the availability of gibberellic acid even if seeds were not stratified for 90-120 days. Seeds with the indeterminate type of dormancy derive from excised embryo normal seedling production. Germination occurs in the availability of gibberellic acid in some species. To break the dormancy of seeds it is necessary to stratify seeds for 90-120 days. This period can be shortened to store dry seeds. On the other hand, for seeds with nondeep dormancy normal seedling production takes place from the excised embryo. The availability of gibberellic acid enhances germination. Cold (0-10°C) or warm (up to 15°C) stratification breaks seed dormancy depending upon species. Ripening of seed may occur after dry storage. Scarification of seed may enhance germination.

1.14 FACTORS RESPONSIBLE FOR SEED DORMANCY IN PALMS

Various factors cause seed dormancy i.e., hard seed coat, underdeveloped embryo, temperature, light, moisture contents, presence of inhibitors, etc.

1.14.1 Hard seed coat

Seeds with hard seed or fruit coats are impermeable to water and oxygen which are the essential requirements for the germination of a seed, causing dormancy in seeds.

1.14.2 Embryo immaturity

The embryo of some species may not be fully developed when the seeds are dispersed and shed. In such cases, the dormant period is necessary for embryos to gain germination capacity.

1.14.3 Presence of inhibitors

In fruit or seed coats, dead embryos or endosperms of some species have growth-inhibitory chemicals which delay germination and cause dormancy.

1.14.4 Light

Some plants' seeds have a sensitivity to light. In those cases, in which light reaches to seed cannot germinate, whereas seeds of some plants are very hard and do not germinate when exposed to light for maximum duration.

1.14.5 Temperature

Downfall in temperature also plays a significant role in the germination of seeds. Seeds of some plants germinate when the temperature becomes low. Some species of Amaryllidaceae germinate after ice melts. On the other hand, for seeds of some taxa, high temperature is required and without its availability can’t germinate.

1.15 GERMINATION

Germination is a phenomenon that consists of those phases that start with the availability of water by the dormant dry seed and complete with the elongation of the embryonic axis

(Bewley and Black (1994). It is of two types epigeal and hypogeal. Many authors contributed to the alleviation of seed dormancy in various taxa.

Our interest family is Arecaceae, so here we focus on seed germination and dormancy in Arecaceae (Palmae) which comprise about 2600 species. Members of the family are evergreen trees, shrubs, and liana. It is distributed in tropical and subtropical areas of the globe (Mabberley, 2008). Palm fruits are fibrous drupes or berries with up to 10 seeds. However, the fruit of most palm species has only a single seed per fruit, while they may be tri-carpellary. Palm fruits show great diversity in size. *Lodoicea maldivica* (double coconut) has the largest seed in the plant kingdom, ranging from 45-50 cm long and weighing up to 36 Kg. Generally, the pericarp (fruit wall) comprises the exocarp (outer layer), mesocarp (middle layer) and endocarp (inner layer). The endocarp may be thin, thick, or stony (drupe) in some taxa fleshy or papery (berry) while in some it is undifferentiated (Dransfield and Uhl, 1998). The endosperm of a palm seed is a bulk of nutritive tissues that provides food to germinate seedlings for a longer period than what is found in most other angiosperm families. The endosperm of some species may be hard or soft, as in the case of coconut liquid (Meerow and Broschat, 2004).

1.15.1 Types of germination in palms

In the palm family, two different types of germination exist, i.e., remote and adjacent. In remote germination, the development of the seedling axis occurs at some distance from the seed and is called the cotyledonary petiole. Many people consider it the first root to emerge from the plantlet. The cotyledonary petiole grows downward into the soil and swells at the basal position. The emergence of the radicle (root) and plumule (shoot) occurs from this swelling portion. The actual seed leaf or cotyledon remains inside the diaspore, functioning as a haustorium. The nutrient transport from the endosperm to the young plantlet takes place through a haustorium. The seeds of some genera such as *Phoenix*, *Chamaerops, Livistona, Washingtonia*, etc., have a remote type of seed germination. Moreover, in adjacent germination, only a small part of the cotyledon emerges from the diaspore. Its appearance is like a swollen object adhering to the surface of the diaspore and is known as a “button”. The root and shoot emerge from the top and buttocks of the button. In palm species with adjacent germination, the first radicle of the seedling is usually narrow and very short-lived and ultimately converts into a root formed at the plantlet’s stem base. In the case of remote germination, the haustorium remains in the endosperm of the palm endospore. *Cocos, Nannorrhops, Archontophoenix, Dypsis,* etc., are palms with remote germination.

Many authors studied dormancy in palm species of different zones on the globe. Some of them are mentioned in the following paragraph. The seed structure and germination of the *Mauritia flexuosa* is studied by (Silva *et al*., 2014), studied the seed structure, and germination, of *Butia capitata* (Oliveira *et al*., 2013). A review is available on the seed biology of palm from (Segovia *et al*., 2003), who carried out Storage and germination treatments for seeds of the ornamentally important palm, *Saribus rotundifolius* studied by (Sanjeewani *et al*., 2013). The effect of dry heat treatment along with some dormancy-breaking chemicals on *Elaeis guineensis* Jacq. oil palm seed germination is recorded by (Tabi *et al*., 2017). What kind of seed dormancy palms might have? been an important contribution of Baskin and Baskin, (2014). Endocarp removal enhances *Butia capitata* (Mart.) Becc. (pindo palm) seed germination is studied by Broschat (1998). Dormancy and germination in four palm species namely *Arenga australasica, Calamus australis, Hydriastele wendlandiana* and *Licuala ramsayi* studied by Latifah *et al*., (2014).

Various regions hosting forest vegetation are comprised of palm species i.e., the Amazon, Madagascar and different forests of Southern Asia. Southern Asia is a vast and ecologically rich region in terms of plants and animals and hosting marvelously diverse palm flora. The region has 43 genera and 352 species of rattan and palms distributed in Thailand, India, Pakistan, Bangladesh, Afghanistan, Japan, Myanmar, China, Cambodia, Srilanka, Bhutan, Nepal, Laos, Taiwan, and Vietnam (Henderson, 2009). In Pakistan, Arecaceae is represented by 16 genera and 18 species. Among these 14 genera and 15 species are cultivated and 2 genera and 3 species are wild (Riffle, 2011). *Nannorrhops ritchiana* (Griff) Aitch is an important keystone species that occur in different regions of Pakistan, Iran, Afghanistan, Saudi Arabia and Oman (Abdullah *et al*., 2020). The species has a broad ecological amplitude and distribution, and it can survive in severe sorts of climatic conditions which leads to morphological diversity in the species (Lackner, 2003).

1.16 **TAXONOMY OF *NANNORRHOPS RITCHIEANA***

Based on morphological features two species of the genus *Nannorrhops* have been recognized, i.e., *Nannorrhops ritchieana* and *Nannorrhops baluchestanica*. In this thesis, we focus only on *Nannorrhops ritchieana.* It is a gregarious shrubby hapaxanthic, hermaphroditic fan palm, its leaf lacks hastula (Tomlinson, 1961), the stem is erect and dichotomously branching, the inflorescence is supra-foliar and compound (Morrow, 1965; Uhl, 1969).

1.17 MORPHOLOGY

1.17.1 General Description

The stem is usually shrubby, but some old plants reach tree height. The stem is branched, erect, or prostrate, and prostrate branches arise from the axil of the trunk whereas in erect stems branches arise from the main stem in a dichotomous pattern.

1.17.2 Leaves

The leaves are marcescent, briefly costa-palmate and induplicate. The leaf sheath splits below and opposite the elongated petiole. The sheath is tomentose, covered by brown wool-like soft fibers, with frayed margins that develop into thread-like fibers. The blade lacks a hastula and is regularly divided into single-fold glaucous segments. The segments are furtherly divided by abaxial splits. The filaments between two segments are conspicuous, midribs occur abaxially, and the transverse veinlets are obscure.

1.17.3 Inflorescences

Nannorrhops ritchieana produces an unspecialized compound inflorescence (Tomlinson and Moore, 1968). It arises above the leaves and consists of a few branches. Each floral branch is subtended by a small leaf or a tubular bract. Two-keeled, tubular prophyll characterized by similar peduncular bracts are zero to several in number. The rachillae produce conspicuous tubular bracts, that are tomentose, and each subtends a cluster of flowers.

1.17.4 Flowers

The condensed cincinnae have 1-3, sometimes up to seven pedicellate flowers. Each flower has a short tubular bracteole and a thin calyx. The corolla has three distinct lobes and a minute stalk-like base. The stamens are six in number, antesepalous with free filaments and antepetalous, the filaments are adnate to the petals at the base. Elongate anthers, carpels three in number and the flower have a distinct ovary with three grooves. There is a single style with the stigma scarcely differentiated and an anatropous ovule attached at the ventral and basal sides. Redundant stamens 6, distinct, the antesepalous with free filaments, and the antepetalous with filaments adnate at the base to the petals, the filaments are awlshaped, inflexed at the tip, the anthers are elongate, versatile, latrorse; there are three carpels which are connate except at the very base, the ovary distinctly 3-grooved, style single, stigma scarcely differentiated, ovule anatropous, attached ventrally and basally.

1.17.5 Fruit

The one-seeded fruit varies from subglobose to ellipsoidal, and it has a smooth epicarp, fleshy mesocarp and thin endocarp. The seed is round to oval with a basal hilum. The endosperm is homogenous and usually characterized by a small central hollow and a basal embryo.

1.17.6 Root

Nannorrhops ritchieana like other palms has an adventitious root system. Producing numerous, relatively small and non-woody roots. Primary roots are almost of equal diameters throughout, and they periodically or independently arise from the root initiation zone. Roots store a considerable quantity of minerals and water and therefore are important for transplantation from one place to another.

Figure, 1.1 Mature plant of *Nannorrhops ritchieana*

1.18 THREATS TO NANNORRHOPS RITCHIEANACONSERVATION

Nannorrhops ritchieana populations are decreasing due to various biotic and abiotic factors. Some major factors that are involved in the degradation are anthropogenic pressure, soil erosion, road construction, unplanned afforestation, unplanned cutting, insect attacks during blooming, flower plucking by kids, seed dormancy, grazing, uprooting by porcupine (*Hystidix histida*) and bear (*Ursus*), etc.

1.18.1 Overexploitation

The human population is increasing day by day throughout the globe. It is a fact, that a large population has enormous requirements. Most of these requirements are fulfilled by the surrounding plant ecosystem. People use plant resources for therapeutic purposes, fuel, construction, clothing, fibers, ropes, utensils, oil, nutritional, aesthetic as well other purposes. *Nannorrhops ritchieana* is among the highly used plant species that provide multiple ecosystem services. It has a vital role and contributes to the livelihood and socioeconomic security of indigenous societies. Leaves of this robust palm are used in the production of different utensils, goods and handicrafts, e.g., house roofing, fences, mats, baskets, large prayer mats, hand fans, small prayer mats, trays, hot pots, brooms, grain bins, hats, cultural sandals, rosaries, toothbrush, etc. These multiple ecosystem services have led to anthropogenic pressure and overexploitation of the species in our study area.

1.18.2 Grazing pressure

Grazing pressure is a serious threat to *Nannorrhops ritchieana* in its wild habitat. The local communities graze cattle such as goats, sheep, calves and cows in the wild habitat which severely devastates new seedlings of the species. Grazing animals also feed on mature plants' young inflorescences and fruits.

1.18.3 Soil erosion and sand mining

Soil erosion and sand mining is a serious threat to *Nannorrhops ritchieana* populations. Local communities collect soil for different purposes. According to Abdullah *et al*. (2019), the species grows in a special type of soil red colour in Bajaur while in other districts it mostly occurs over the talc rocks. Local people from adjacent villages come to collect that red colour soil for their house painting purposes. They formed gullies due to the maximum collection and a high number of individuals have been removed.

1.18.4 Road construction

Road construction as part of the China-Pakistan Economic Corridor (CPEC) is in process in different cities of the country (Nabi *et al*., 2017). It is a big economic corridor worth more than 51.5 billion USD organized between China and Pakistan (Kiani, 2016). It is comprised of different projects and infrastructures including a network of highways between different cities across the country (Shah, 2015). The CPEC is very important from a socio-economic point of view but on the other hand, it is detrimental to our native threatened biodiversity (Nabi *et al*., 2017). *Nannorrhops ritchieana* is also among the plant species whose populations are mainly devastated by different factors and among them road construction, particularly the CPEC routes construction is a major one. In different regions such as Bajaur, Mohmand, Orakzai and D.I.Khan a bulk of mature *Nannorrhops* plants with their associated vegetation have been devastated.

1.18.5 Unplanned plantation

In the billion-tree tsunami afforestation program (BTAP) some wrong plant species have been planted in the wrong places, i.e., *Eucalyptus* species of the moist and water-rich habitat are planted in the natural habitat of *Nannorrhops ritchieana*. It is a serious threat to *N. ritchiana* and its associated local plant species, i.e., *Dodonaea viscosa*, *Olea ferruginea*, *Gymnosporea royleana*, *Periploca aphylla*, etc. The water level of underground water was already affected by the dramatic encroachment of climatic catastrophes.

1.18.6 Uncontrolled cutting

Uncontrolled cutting is a serious problem for the conservation of *Nannorrhops ritchieana*. In most of the indigenous localities various parts of the palm are harvested during its early stages. The suitable season for the collection of *Nannorrhops ritchieana* leaves is from Oct — Jan.

1.18.7 Insect attack during blooming

During the blooming period of *Nannorrhops ritchieana* (May— July), various insects attack its long inflorescence, during which several flowers are damaged and destroyed which not only affects fruit production but also seeds which are an important source and entity for its propagation and conservation.

1.18.8 Flower plucking by children

During the blooming season, children pluck the inflorescence or collect its fruit before ripening in wild. Mostly in cultivated form, the farmers cover it with bags formed of jute fibers to protect it from insects and children's attacks.

1.18.9 Uprooting by animals

Porcupines (*Hystrix histida*) and bears (*Ursus*) are involved in uprooting the *Nannorrhops* plants in their natural habitat. These species feed on its root for food mostly in the winter season. Other burrowing animals in the soil also dig out *Nannorrhops* roots. This phenomenon is considered a serious threat to the conservation of this important palm species.

1.18.10 Species long life cycle

The long-life cycle is another challenge for conservation and propagation of this palm. It takes around 3—4 years to produce the first leaves, and the individuals take 7—12 years to reach the juvenile stage. The plant takes 23—40 additional years to reach the reproductive stage and start fruiting. Wild populations were mostly represented by older plants whereas juveniles and seedlings were very fewer in number. It shows that in the future it will be challenging for juveniles and seedlings to cover the gap of old individuals (Abdullah, 2019).

1.18.11 Agricultural expansion

The continuous increase in human population leads to increased demand for food, health, livelihood and many other basic needs of life. Humans use and convert natural habitats into agricultural fields, large buildings, residential sectors, hospitals, etc. Food security is an important and serious issue in developing countries. Pakistan is among the developing countries with a big mass of human population. To feed such a great population the farmers convert indigenous habitats into agricultural fields which is a serious threat to the population of *Nannorrhops ritchieana.* In 1953 the government of Pakistan devised roles and regulations for the management of *Nannorrhops ritchiean a*population in the natural ecosystems of Kohat. People of different regions other than Kohat division use to convert *Nannorrhops ritchieana* habitats into agricultural fields.

1.19 SCOPE OF THE STUDY

Nannorrhops ritchieana is an important palm species that provide a multitude of ecosystem services. Considering the importance of *Nannorrhops ritchieana* and the threats leading to its population destruction, the current study was designed. We focused on the multifold ecosystem services, socioeconomic importance, population ecology, and associations of *Nannorrhops ritchieana* with other plant species and to overcome its seed dormancy and enhance germination with a long-term management plan. According to the best of our knowledge, by reviewing an extensive literature there is no detailed published information regarding the ethnobotany and socio-economic of *Nannorrhops ritchieana* across different ethnic groups. Our study on the population ecology, associations/communities and seed dormancy and germination ecology of this palm is the first ever. Moreover, all the abovementioned aspects of *Nannorrhops ritchieana* were studied in detail for the last four years. We hope this dissertation and the papers published from this study will serve as a baseline and will provide in-depth knowledge and information to palm biologists, economists, nursery growers and government agencies working on palm conservation.

1.20 RESEARCH HYPOTHESIS

The extensive literature reviews, exploration and experimentation in the current study commence with the following hypothesis.

(i) The traditional knowledge regarding different provisioning ecosystem services i.e., handicrafts, goods and utensils processed varies across different regions of the study area inhabited by diverse communities.

(ii) *Nannorrhops ritchieana* population is decreasing in the study area due to different biotic and abiotic factors. ii. Fruiting ecology is controlled by plant height (age groups).

(iii) *Nannorrhops ritchieana* being a gregarious species leads to the formation of different sorts of associations under the influence of various environmental factors.

(iv). Seed dormancy is a critical problem for *Nannorrhops ritchieana* population conservation which might be mitigated by using various chemicals in different concentrations and time intervals.

1.21 AIM AND OBJECTIVES

The overarching aim of this thesis was to document the *Nannorrhops ritchieana* multifold ecosystem services, socioeconomic importance, population ecology, its association with other plants species and to overcome its seed dormancy and enhance germination for developing a long-term management plan the current study aimed to:

(i) assess the importance of *Nannorrhops ritchieana*in terms of ecosystem services and understand what determines the community-specific utilization based on the availability of plant material and the indigenous knowledge that the community possesses.
(ii) quantify *Nannorrhops ritchieana* individuals in different age classes across different populations and to know what factors control the effect of different age classes on the inflorescence size, fruit number, fruit size and seed size.
(iii) explore various associations of *Nannorrhops ritchieana* and its associated flora across different zones of the study and identify what environmental gradients are responsible for the establishment of such associations.
(iv) disentangle the impact of H2SO4, HNO3, Thiourea, Hot water, GA3 and IAA in different concentrations and immersion times and comprehend what other factors trigger seed dormancy and delay germination.

1.22 THESIS OUTLINE

This dissertation consists of seven chapters: Chapter 1, a general introduction, Chapter 2 study area, four research chapters (3, 4, 5,6), and the final synthesis (chapter 7), In chapter 1, we present the background of ecology, socioeconomics, ethnobotany and seed dormancy in the *Nannorrhops ritchieana*. In Chapter (2) we brief you about the study area and in Chapter (3) we emphasize the ecosystem services of *Nannorrhops ritchieana* (provisioning services in the form of various handicrafts) with their socioeconomic role across different regions inhabited by different cultural groups. In Chapter (4) we discussed different aspects of population ecology with a special focus on its fruiting ecology in relation to plant height. Chapter (5) disentangles how various environmental variables affect *Nannorrhops ritchieana* and its associated flora across the study area. This chapter portrays the total classification of all zones by using Cluster analysis and other multivariate techniques. In chapter (6) we evaluate the challenge of seed dormancy and its solutions by using different types of chemicals in various concentrations with different immersion times. Finally, we synopsize the overall picture of the thesis outcomes in Chapter (7) synthesis by discussing them in the light of existing knowledge.

CHAPTER 2

STUDY AREA

2.1 STUDY AREA KHYBER PAKHTUNKHWA PROVINCE

The province of Khyber Pakhtunkhwa is a topographically diverse region of Pakistan. It is in the northwest of the country at 31°49′–35°50′N longitude and 70°55′–71°47′E latitude (Jan *et al*., 2019). The province covers an area of 101,741 square kilometers (https://kp.gov.pk). It shares a long border in the northwest at the Durand line with Afghanistan. Punjab is in the southeast while in the east, the province is bounded by Azad Kashmir while in the southwest it has a boundary with the Baluchistan province. The land mass of the province is an abode to the world's three different mountain series namely the Hindukush, Himalaya, and Karakoram (Anonymous, 2016). These mountainous ranges occur in the northern, northwestern, and eastern parts of the region. Various peaks of these mountains are covered with snow throughout most of the year and hence northern parts experience cold and snowy weather with a pleasant breeze and heavy rainfalls in the winter as well as in the summer. On the other hand, the southern parts of the province are dominated by central plains and valleys. The southern plains of Khyber Pakhtunkhwa are characterized by a normally cold winter and hotter summer with moderate rainfall. Chitral in the north of the province is the district with the highest altitude, experiences the lowest temperature in winter and hence hosts many glaciers. On the other hand, Dera Ismail Khan in the south of the province experiences the lowest temperature in winter with an optimal climatic opportunity for agriculture. Pashtun or Pathan is the leading nation living in the valleys of Khyber Pakhtunkhwa (Aman, 2013). The nation is further divided into tribes and sub-tribes as given in the following section of ethnography.

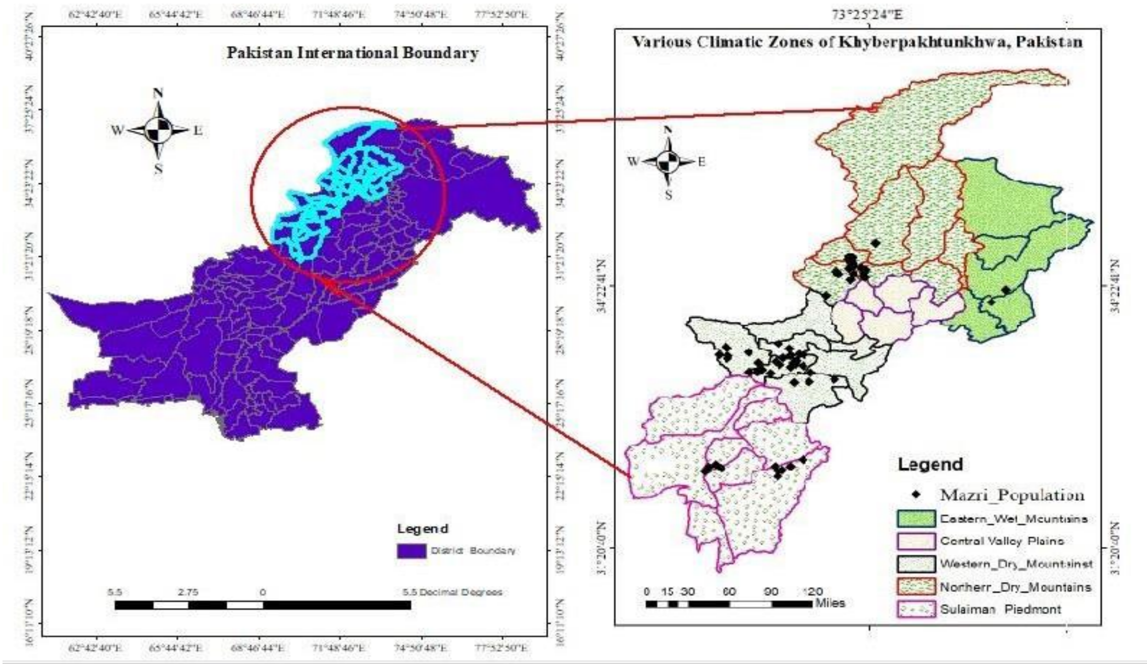


Figure 2.1 Map of the study area (constructed with Arc-Map)

2.2 CLIMATE OF KHYBER PAKHTUNKHWA

Topographically Khyber Pakhtunkhwa is a diverse region of the country. The mountain series in the region (Hindukush, Himalayan and Karakoram) have a crucial role in the dynamics and variation of climate (Rahman *et al.*, 2022). These mountains are in the northwestern, northern and eastern parts of the province. On the other hand, the southern parts of the province are comprised of valley plains. This diversity in topography leads to diversity in climatic conditions (Babar *et al.*, 2015). The winter in the northern parts of the province is cold and snowy while the summer is pleasant with heavy monsoon rainfalls. In the southern parts, the winter is not extremely cold, with hot summers and moderate rainfall. The Chitral district has the highest altitude compared to other districts of the province with low temperatures and hence hosts many glaciers (Riaz *et al.*, 2014). Moreover, D. I. Khan is the southernmost district of the province and is characterized by milder winters and hot summers. The central plain valleys of Mardan, Swabi, Charsadda and Nowshera are characterized by milder winters and warm summers, but these regions have a well-managed canal system that plays a significant role in irrigation. December to February is the winter season in Khyber Pakhtunkhwa. In January the temperature in the province is low and precipitation is also scarce. In February the temperature is about 1—4^{O}C and increases occur while precipitation increases from 70—90mm to 200—220mm.

March—May is the spring season in the province, where in March temperature increases and average precipitation goes down. Similarly, from April to June temperature increases and precipitation decreases. It is of great importance for the wheat crop (Khan *et al.*, 2016) because wheat ripening occurs at the end of April and reaches mid-June for which a hot blazing temperature is required. June-August is the summer season in the province. July and August are rainy months in the region and in most areas, monsoons take place. In these months temperature and precipitation are high due to which a considerable increase occurs in humidity as shown in the figure. In September and October, the precipitation and temperature decrease, and this is the start of autumn (September—November). In November and December, the cold increases and hence again winter season starts https://tcktcktck.org/pakistan/khyber-pakhtunkhwa#t3.

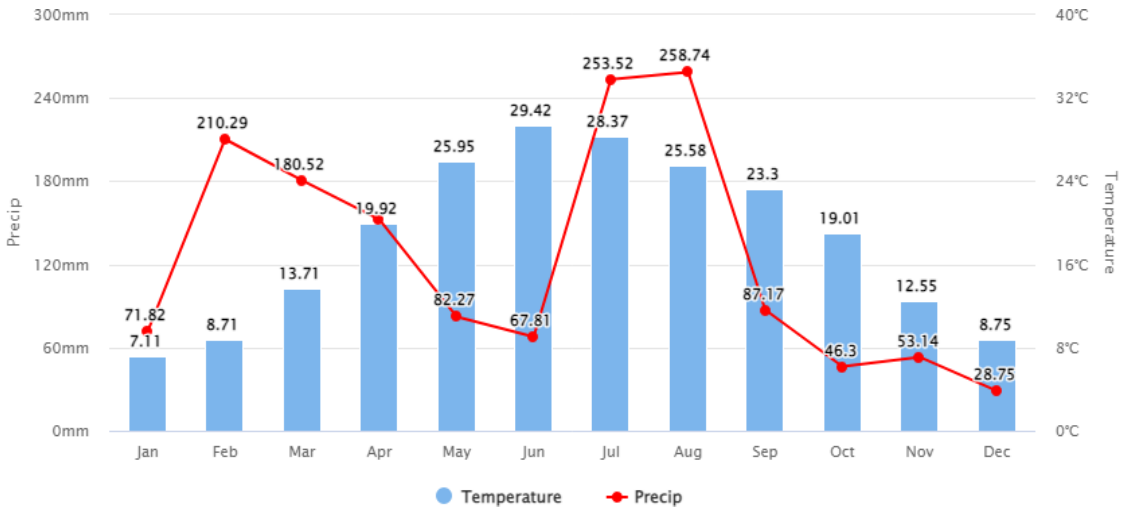


Figure 2.2 Mean monthly temperature and precipitation of Khyber Pakhtunkhwa (https://tcktcktck.org/pakistan/khyber-pakhtunkhwa#t3)

2.3 GEOLOGY

In the early years of Pakistan, it was generally understood that Pakistan was a country of younger orogenic belts and sedimentary basins. The province of Khyber Pakhtunkhwa is rich in mineral resources. There are large deposits of salt in the Bahadur Khel region of district Karak. Marble, Gypsum, limestone and soapstone. Southern Khyber Pakhtunkhwa has the same type of uranium as that of Sui Baluchistan. The region is also the custodian of chromite, China clay, and manganese in the Bajaur Takht region (Bilqees *et al.*, 2014). In Swat, the famous emerald, Copper-gold and lead-zinc exploration in Waziristan is an important addition to the geology of the province. Oil and gas in the Karak in Nashpa (Noreen *et al.*, 2020), Banda Daud Shah and Kohat region, rock phosphate in Hazara, and a variety of gems, and precious stones in the province (Malkani *et al*., 2017). The discovery of coal deposits in Hangu, Orakzai, Dara Adam Khel and Kohat regions (Malkani *et al*., 2013). Mohmand, Khyber, Bajaur and especially district Buner has great deposits of different types of marble stones. Buner has more than 600 marble industries (Ahmad *et al*., 2019; Ahmad *et al*., 2023).

2.4 ETHNOGRAPHY

The name Khyber Pakhtunkhwa is a clear indication that it is a Pashtun region. Mostly inhabited by Pashtun (Bhatti *et al*., 2017) except for a few districts i.e., Abbottabad, Haripur, Kohistan and Mansehra. In these districts, most of the population is of Hindku speakers, while Kohistan is mostly populated by Kohistani people. The Pakhtun or Pashtunis nation is further divided into subtribes or clans (Glatzer, 2002). Yousafzi (Tabassum *et al*., 2017), Khattak, Bangash, Afridi, Orakzai, Dawar, Turi, Mohmand, Achakzai, Shinwari, Utmankhel, Banusi, Marwat, Wazir, Sherani, Mehsood, Burki, Bethani, Adamkhel, Mohammadzai, Khalil, Alizai, Miangan, Kotkhel, Sadozai, Pahari, Mashwani, Wardag, Dalazak, Abbasi, Gujjar (Ullah *et al*., 2017), Kakar, Mandozai, Swati, Udezai, Dawoodzai, Alisherzai, Barkihel, Buneri, Utmankhel, Salarzi, Mamund, Tarkanri, Kakakhel, Katozai, Umarzi, Mengal, Bajauri, Utmanzai, Abbasi, Usamanzai, Syeds, Ghabzi, Qambarkhel, Durrani, Khwazikhel, Niazi and some others. Many of these were mentioned by Musharaf Bangash in his song which could be traced via the following link https://soundcloud.com/jahansher-agha/musharaf-bangash-52-pashto.

2.5 CULTURE

The people of the province go through and experience a centuries-old culture known as Pakhtunwali or Pashtunwali. Pakhtunwali is a very common cultural legacy of the Pathan communities living in Khyber Pakhtunkhwa. It is a way of life or a legitimate social code of conduct that controls their lives. It is a 2000–3000 years old tradition that continues to be the central pillar of tribal societies (Tainter and MacGregor, 2011, Abdullah *et al*., 2021). In this era of science and technology, Pashtunwali is perceived as culturally distinctive, substantially influencing perceptions, behaviors, and opinions in everyday life. Code of Honor (Nang), hospitality (Melmastia), and revenge (Badal) are the three central pillars of Pashtunwali (Tariq *et al*., 2018). The code of honor is a vital component and feature of Pashtun society. Hospitality is a sum of rules and an urgent reward from local communities regarding traditional cultural values. On the other hand, revenge is like a debt that ends with payback. These three cultural traditions are the sum of Pathan communal expectations from their peoples, as well as from others (Ullah, 2015). There are other cultures like Hindku, Chitrali, and Kohistani but here I focus only on the most prominent and dominant ones.

2.6 FOOD SYSTEM

The custom of hospitality is related to food. Pathans offer food to each other and safeguard their natural resources. They are well known for their unique traditional food system. As for the food system, it is worth mentioning that people are financially poor. They mostly collect wild vegetables and fruits from surrounding fields and forests in their territories. Homemade food culture is very common because Pathan people mostly eat at home. Therefore, the practice of eating out in restaurants, huts, and other food points is rare. These habits of Pathan societies and the diverse climatic conditions of the region and its rich flora and fauna strengthen the bond between people and wild food resources (Abdullah *et al*., 2021).

2.7 TOURISM

The province is considered an important tourism hotspot (Sanaullah *et al*., 2020). It has a great advantage in tourism with provincial tourism and a cultural policy. Mostly adventurous and faith-based tourists have a crucial contribution to marketing and fostering the tourism industry in the country (Alam and Ali, 2022). The number of regional tourists increases each year, Kaghan, Naran, Kumrat and Gabin Jaba gained great popularity and the attention of tourists (Qamar and Balouch, 2017). Tourists visit Khyber Pakhtunkhwa from different regions of the country such as Punjab, Sind, and other regions of the country. The climate of the province is moderate and suitable in the summer season and in some regions, it is cold like Ayubia, Galyats, Muree, Madyan Bahrain, Malama Jabba, Gabin Jabba and Kumrat and others (Arshad *et al*., 2018). The tourism industry is an effective tool for the development of cottage-based industry, intangible culture, urban planning, and infrastructure. The region is also an important hub of different civilizations. The Gandara civilization grew up in the gorges of the Indus and still has numerous symbols and signs of this great civilization. Takht Bhai is the center place Buddhist civilization. It is a keepsake or memento of Buddhist civilization. Believers of Buddhism come from different regions of the globe to this historical place (Khattak, 2019). Other important cultural places are Balahisr Fort, Mohabbat Khan Mosque, Pir Baba Mosque, Babi Khyber (Jamrud), Ayub

Qilla, Ilyasi Masjid, Qissa Khwani, Islamia College Peshawar, Sheikh Badin National Park are worthy to be visited.

2.8 DEMOGRAPHY

The population of Khyber Pakhtunkhwa according to the 2017 population census report is 30,508,920. In 2018 Federally administrated tribal areas (FATA) also emerged with Khyber Pakhtunkhwa. The population of FATA is about five million. In 2017 a considerable increase is observed in the population of Khyber Pakhtunkhwa as well as in FATA from 1998 (Ul-Haq *et al*., 2019). Most of the population is living in cities like Peshawar, Mardan, Mingora, Timergar, Bannu, Karak, D.I Khan, Mansehra, Abbottabad and Haripur, Nowshera, Swabi, and Topai, etc.

Table. 2.1 Demography of Khyber Pakhtunkhwa and FATA according to Census 1998 and 2017

Administrative Unit	**Population (1998)**	**Population (2017)**	**% Growth**	**Annual growth percentage**
Khyber Pakhtunkhwa	17,743,645	30,508,920	71.9	2.89%
FATA	3,176,331	4,993,044	57.2	2.40%
Total	20,919,976	35,501,964		

2.9 EDUCATION

Over the last ten years the education percentage has been increasing in Khyber Pakhtunkhwa. During this period the Pakistan Tehreek Insaaf (PTI) government has focused on education. They spend much of their budgets on the development of educational institutions. They strictly observed the teaching system in the region and selected talented young teachers in their two tenures. More than five million students and 33,440 schools in Khyber Pakhtunkhwa have a large education system. About 85% of the children are enrolled in schools. A significant increase (7%) is observed in students and 90% in teachers' attendance (Jehan *et al*., 2021). People migrate from villages to main cities to provide their children with a proper and quality education. Every year thousands of students graduate, and a significant number go abroad. In the province, there are a total of 18 higher education commission (HEC) recognized public universities and nine private universities (Khan *et al*., 2020). In the province, there are about 30 colleges for medical and dental education. Among these 14 are government medical colleges.

2.10 IRRIGATION AND AGRICULTURE

Khyber Pakhtunkhwa is a mostly mountainous region of the country. The local inhabitants are very hard workers, and they grow various crops in the valleys of these rugged and tough landscapes. The region is also abode to a few important rivers and numerous small streams (Khan *et al.*, 2017). Mostly they originate from glaciers and snow melting. Tube wells and dug wells are also important to a segment of irrigation in the region. A huge mass of land especially in southern and southwestern parts of the province called Barani land has only a few streams and is fully dependent on rainfall. In the northern parts of the province monsoon is a crucial source of different crops in the summer season. Wheat, maize, barley, sugarcane, tobacco, mustard, and different types of beans are cultivated. In vegetables, lady finger, various types of pumpkin, tomato, onion, garlic, cauliflower, eggplant, shimla, potato and many others are cultivated. The region is also very popular for different types of fruits such as apples, pears, peaches, apricot, plum, almond, walnut, mulberries, strawberries, oranges, watermelons, melons, and various others. Moreover, Khyber Pakhtunkhwa is well blessed with different natural resources. In some regions, water is so scarce that for drinking people use pond water. In these regions, their animals also drink from the same ponds. In Sheikhbadin national park during the British era, they developed 12 ponds for the collection of rainfall water. Now they are still used by the local people and their animals as shown in the figures.

2.11 LIVELIHOOD AND SOCIOECONOMIC

In Khyber Pakhtunkhwa, hardworking people go abroad to Saudi Arabia, Malaysia, Arab Emirates, America, Canada, Qatar, Kuwait, Poland, England, Scotland, France, Italy and various other countries. They provide a significant number of remittances to their families. Locally, small industries are also run by people such as marble industries which are very common in Buner, Khyber, and Mohmand. In minerals talc, chromite, manganese ores, and iron ores. On the other hand, the cement industry also plays a crucial role in the economy of the region. Farming, cattle rearing, coal mining, business, poultry farms government jobs, etc. are very common professions in the region. Moreover, Karak, Hangu, and Kohat are the districts where gas is available. Karak Bahadur Khel salt mines are also an important source of the economy of Khyber Pakhtunkhwa and the whole country. The people of Khyber Pakhtunkhwa also work in other parts of Pakistan i.e., Lahore, Karachi, Multan, Quetta, Faisalabad, Sialkot, Rawalpindi, Islamabad, and others. People of FATA process various types of handicrafts from the leaves of *Nannorrhops ritchieana* which is an important source of economy for the poor societies of the region. The region also has a great tourist industry which contributes to the livelihood and socioeconomics of the region.

2.12 FLORA OF KHYBER PAKHTUNKHWA

The topographically diverse Khyber Pakhtunkhwa hosts diverse plant biodiversity. Keeping in view the climatic variability and forest diversity, the vegetation of Khyber Pakhtunkhwa can be classified into eight different forest types or covers. The flora in the plains of D.I.Khan is comprised mostly of xerophytic species such as *Acacia modesta*, *Phoenix species*, and *Periploca* species. The Lakimarwat, Kohat and Karak regions have *Capparis decidua*, *Acacia nilotica*, *Prospis juliflora,* and the rare *Tecommela undulata*. These regions are characterized by the scrubby appearance of the vegetation. The Hangu region's vegetation is different from these districts, dominated by *Grevia* species, *Olea ferruginea*, *Sideroxylon mascatensis* and *Dodonea viscosa*. Along the Hangu region, Kurram valley is located which is different from these regions and occurs at a high elevation. The region has cold climatic conditions and is mostly inhabited by Himalayan Plants. Common plants are, *Nannorrhops ritchieana*, *Punica granatum, Quercus* species and *Juglans regia*. The region also hosts a few endemic species such as *Rhododendron afghanicum*, *Seriphidium kurramens*, *Vincetoxicum cardiostephanum*, *Pseudomertensia anjumiae*, *Rhododendron afghanicum* and *Nepeta kurramensis*. Kurram river is the main source of irrigation in the region. Orakzai district is located along the Kurram Valley in the east. Both regions share the maximum plant species in the upper regions (in the transition zone). Orakzai is poorer in terms of plant species than Kurram. *Pinus roxburghii, Nannorrhops ritchieana*, *Quercus* species, *Acacia modesta*, *Grevia* species, *Olive ferruginea, Punica granatum*, and *Buxus* species are characteristic of the region. Orakzai in the east is bordered by the district Khyber. Khyber is a dry district and currently, its vegetation is severely affected by the invasive tree species *Prospis juliflora*. Common species in the region are *Acacia modesta*, *Periploca aphylla*, *Capparis decidua*, *Calotropis procera* and the most popular herb species *Peganum harmala*. The Khyber district is separated by the river Kabul from the district of Mohmand. Mohmand is a mountainous area comprised of xerophytic and thorny vegetation. Common plant species are *Acacia modesta*, *Nerium* species, *Sideroxylon mascatensis*, *Ziziphus oxyphylla*, *Adhathoda vesica* and *Dodonaeae viscosa*. The region is located on the border of Bajaur where the high mountains prevent the cold rainy winds from entering the region. Bajaur is the last tribal district of ex-FATA in the north. It is colder than Mohmand and hence hosts a great diversity of plants. *Pinus roxburghii*, *Sideroxylon mascatensis, Myrtus communis, Ficus carica*, *Morus alba, Morus nigra, Melia azedarch, Quercus* species and *Celtis australis* are common in the region. Some regions like Mamund tehsil and Salarzai tehsil receive monsoon rainfall from June to the end of August which increases the vegetation cover and composition. K-More is the highest peak about 3000 meters high in the region. Bajaur is bounded by district Dir in the East and Malakand in the Southeast. District Dir Lower and Bajaur have great homology in plant species and both have relatively similar climatic conditions. River Panjkora separates it from Bajaur from district Malaakand. Malakand is considered an important hotspot for various plant species i.e., *Pinus roxburghii, Dodonaea viscosa*, *Acacia modesta, Bauhinia variegata*, *Nannorrhops ritchieana*, *Morus* species, *Melia azedarch, Periploca aphylla, Grevia species, Nerium oleander* and various types of grasses. Moreover, the Hazara division is the botanically rich region of Khyber Pakhtunkhwa that hosts diverse flora. The characteristics species include *Pinus wallichiana*, *Pinus roxburghii*, *Picea smithiana*, *Cedrus deodara*, *Ulmus wallichiana*, *Aesculus indica*, *Debregasia saenab*, *Cretagus sonagarica*, *Pyrus psuedopashia*, *Robus* species, *Woodfordia fruiticsoa*, *Quercus semicarpifolia*, *Quercus glauca* and several pteridophytes species (Stewart, 1982).

2.13 FAUNA OF KHYBER PAKHTUNKHWA

The diverse ecosystems of Khyber Pakhtunkhwa with many types of forests attract and host rich fauna. Rich bird diversity is present in Khyber Pakhtunkhwa. Chakor, parrot, Miana, crow, dove, sparrow, pigeon, owl, peacock, kalij pheasant, monal pheasant, ducks, wood packer, quail, goldfinches, Himalayan snowcock, anteater, and many others are the common birds of the region (Grimmett *et al*., 2008). In terms of mammals, goats, sheep, cows, buffalo, camels, donkeys, deer, markhor, horse, dog, fox, rabbits, porcupines, monkeys, leopards, bears, bats, etc. are very common (Shah, 2011). Snakes (different types), lizards, pangolins, turtles, gecko leopards and many others (Hamid *et al*., 2021). are common reptiles. Himalayan toad, Swat green toad, Asian common toad or Black-spined toad, Indus valley toad, Hazara torrent frog, Indus valley bullfrog etc. are common amphibians (Hamid *et al*., 2021). Moreover, about 85 different fish species are reported from Khyber Pakhtunkhwa. The commons are the raho, trout, mahaseer, blind dolphin and a few eel species.

CHAPTER 3

The *Nannorrhops ritchieana* (Griff.) Aitch. cottage industry is a promising source of livelihood in Khyber Pakhtunkhwa, Pakistan

3.1 INTRODUCTION

Plants and plant-based materials have always been components of indigenous cultures throughout the world since ancient times. Plants fibers have been of prime importance in almost all human societies. The history of processing plant fibers is more than 10,000 years old (Mwaikambo, 2006). The use of fibers in handicrafts, utensils and other goods has significantly contributed to the evolution of cultures and ultimately people's consolations (Thomas *et al*., 2012). Many plants fiber-based goods are associated with domestic activities such as the preparation of food, clothing, and furniture (Nedelcheva *et al*., 2011). Palm species are the most iconic and idiosyncratic in fiber production and have been used for more than 10,000 years (Roosevelt., 1996). Palms leaves have maximum flexibility for various utilizations and hence maximum harvesting rate in indigenous societies (Brokamp *et al*., 2011; Cámara-Leret *et al*., 2017). Moreover, palms are an outstanding source of raw materials for construction, clothing, medicines, and other cottage industries and are preferred culturally (Burkill, 1985; Gabriela *et al*., 2023).

All palm species are of prime importance to the indigenous communities of the globe in general and in Pakistan in particular. The palm family Arecaceae is represented by 16 genera and 18 species in Pakistan, out of which 14 genera and 15 species are cultivated and two genera and three species are wild (Riffle, 2011). *Nannorrhops ritchieana* (Griff.) Aitch. is one of these species native to Pakistan, Afghanistan and Iran (species distribution is given in full detail in the Introduction chapter of this dissertation). It is a gregarious and versatile palm that can grow in intense winds, severe cold, blazing heat, and water-scarce types of habitats (Naseem *et al*., 2005).

Nannorrhops ritchieana plays a significant role in the livelihood of indigenous people. A considerable population is involved in the cultivation and handicrafts formation from the leaves of this robust palm (Gibbson and Spanner, 1995). The harvesting period of this plant usually ranges from October to February. A single leaf yields about 30—40 small leaflets. Five kilograms of dry leaves generally gives about four kilograms of products usually with 20% of waste materials (Iqbal, 1991). *Nannorrhops ritchieana* due to its hard and flexible texture is mainly used for weaving different utensils and for rope formation (Abdullah *et al*., 2019; Thomas *et al*., 2012). Historically the leaves and stems have been utilized in mats, fences, and house roofing (Goodman and Ghafoor, 1992). Leaves alone are used to manufacture hand fans, baskets, brooms, trays, small and large prayer mats, grain bins, hot pots, hats, and sandals (Marwat *et al*., 2011). The reddish moss-like wool of the petioles of *Nannorrhops ritchieana* is also utilized as tinder. Fruits of *Nannorrhops ritchieana* are edible, while its hard-coated seeds are used to prepare rosaries (Panhwar and Abro, 2007). Dried leaves, stems, and peduncles are used as fuel. In different parts of Europe and America, it is cultivated in gardens for its aesthetic values (Mahmood *et al*., 2017). In short, its most peculiar uses are in the preparation of traditional products. These products are on the verge of extinction due to (1) a reduction of the populations of this palm, (2) losing ground for specific ethnobotanical knowledge and (3) the availability of synthetic fibers in the market under triggered trends of globalization, industrialization, and communication. Keeping in mind the immense importance of *Nannorrhops ritchieana* palm multifold ecosystem services, ancient art-based ethnobotanical knowledge of rural communities, human encroachment on rural areas, and various natural threats to this plant, the current study was had the specific objectives as follows.

1) To document the importance of *Nannorrhops ritchieana* in terms of ecosystem services especially provisioning and cultural services, 2) To identify the community-specific utilization of *Nannorrhops ritchieana* based on the availability of plant material and the indigenous knowledge that the community (ethnic group) posses. These research perspectives were guided by the wider conservation-related perspective to create possible respect for the value for this *Nannorrhops ritchieana* in the scenario of its cultural, economic and environmental significances. It was the hope that the research could be used to advocate the potential of this palm in the development of future cottage industries, environmental sustainability and traditional ecological knowledge resilience to a wider range of human societies regionally as well as globally via this dissertation.

3.2 MATERIALS AND METHODOLOGY

We focused on *Nannorrhops ritchieana* cultivation, handicraft manufacturing and marketing districts of the province and other districts of the country (as we published in the article by Abdullah *et al*., 2020) but here I will focus only on the districts of my study area in the Khyber Pakhtunkhwa province. In Khyber Pakhtunkhwa province the most noteworthy hotspots for *Nannorrhops ritchieana* handicraft production are Kohat division (Kohat, Hangu and Karak), Dera Ismail Khan, Bajaur, Bannu, Jhandai Mardan, Lundkhwar Mardan, and few regions of district Mohmand. Moreover, the marketing regions include Timergara, Dir Lower, Qissa Khwani Bazar Peshawar, Mansehra, Haripur, Charsadda, Mingora Swat, and Pir Baba Buner. Handicrafts formed from the leaves of *Nannorrhops ritchieana* are a common source of livelihood in the region. Leaves are processed for making various handicrafts as well as sold in the nearby regions in fresh forms.

3.2.1 Ethno-botanical data collection through questionnaires

Fieldwork was done from the spring of 2017 till the autumn of 2021. *Nannorrhops ritchieana* growers, farmers, handicraft manufacturers, middlemen, shopkeepers, and people related to *Nannorrhops ritchieana* marketing were selected as focus groups. These focus groups were classified into two classes based on their location. Focus group one included *Nannorrhops ritchieana* growers, local farmers, manufacturers, middlemen, and marketing people who lived predominantly along the Pakistan-Afghanistan border. Focus group two included a business community or shopkeepers who were localized in very specific markets in various urban regions of the country. These two different focus groups were visited and interviewed via seventy-seven questionnaires.

Table 3.2.1 Questionnaire for the data collection related to handicrafts prepared from *Nannorrhops ritchieana*

<table>
<tr><td colspan="2">Questionnaire No.: ……..…..   Date:</td></tr>
<tr><td colspan="2">Name: …………………………   Gender: (Male / Female)
Age: …………………………..   Education: ………………………….
Profession: ……………………   Location: ……………………………</td></tr>
<tr><td>S. No</td><td>Focus Group-I: (a) Local Palm Growers/ Farmers, Manufacturers, Middlemen and Marketing People</td></tr>
<tr><td>1.</td><td>How much area have you cultivated with Nannorrhops ritchieana? ....</td></tr>
<tr><td>2.</td><td>How much time did you need to start Nannorrhops ritchieana production? ....</td></tr>
<tr><td>3.</td><td>Present Status of Nannorrhops ritchieana in natural environment
a. Increasing: b. Decreasing: c. Stable:</td></tr>
<tr><td>4.</td><td>Genders involved in Nannorrhops ritchieana collection.
i) Male   ii) Female</td></tr>
</table>

5.	Season of *Nannorrhops ritchieana* collection. i) Summer ii) Winter iii) Spring iv) Fall
6.	What is the price for 50 Kg of *Nannorrhops ritchieana* leaves?
7.	Who are the buyers of *Nannorrhops ritchieana* leaves? (i) Local People (ii) Local Contractors (iii) Direct Market Sellers.
8.	What sort of local handicrafts/utensils do they prepare from the *Nannorrhops ritchieana* leaves? ……………………………………..…………………………
9.	Is the business of *Nannorrhops ritchieana* beneficial to the local community? Yes/No If yes, explain how it contributes to the socioeconomics of the locals. ……………
10.	Is it used for ornamental purposes? Yes/No
11.	Is it used for medicinal or nutritional or other purposes? Yes/No If yes, then what sort of use? ……………………………………………………
12.	What purpose do you use *Nannorrhops ritchieana* for? ....
13.	Do you produce handicrafts from *Nannorrhops ritchieana*? Yes/No If yes, then what? ………………………………………..
14.	How many and which of the items do you currently sell in a calendar year?
15.	What is the average price of each product? Name of the product: …………………….. Price per item: ……………………
16.	Where are your primary customers? i) Local villagers/community people (ii) Neighboring shopkeepers (iii) others ….
17.	Are you interested in introducing and developing your handicrafts in new/bigger markets? Yes/No
18.	What do you need to develop your handicrafts? ....
Focus Group II: Business Community and Shopkeepers	
19.	Who are your main suppliers and from where?.......................………………………
20.	How many traditional handicrafts of *Nannorrhops ritchieana* do you sell? Name it also shows us for photography, possibly………………….………………………………
21.	What kind of handicrafts has high market demand? Name, please.………………….
22.	What features do you consider important when you buy handicrafts? ………………..
23.	What kind of handicrafts have a high price? Name as well as price!………………..
24.	Is there any specific season of the year that is best for marketing *Nannorrhops ritchieana* products?..
25.	Are the *Nannorrhops ritchieana* handicrafts preferred by Tourists/Visitors?
26.	Do you have a Marketing network/chain in other cities of the country? Yes/No

	If yes, where then. ………………………………………………………………
27.	Do you estimate that the variety and number of such handicrafts have increased, decreased, or remained stable over the last 10 -15 years?…………………………......
28.	Do you have any recommendations or suggestions for the development of *Nannorrhops ritchieana* cottage industry? ....

3.2.2 Field survey

The border regions between Pakistan and Afghanistan were visited and interviews were made with 17 *Nannorrhops ritchieana* growers (12 male and 5 female), 27 *Nannorrhops ritchieana* farmers (all male), 23 handicraft experts/manufacturers (21 male and 2 female), and eight middlemen. We used mainly Pashto and Urdu languages during the interviews. We started our questionnaires from the local *Nannorrhops ritchieana* growers. Inhabitants were briefed about the purpose of the collection of the data. Photographs of the utensils, goods and handicrafts made of *Nannorrhops ritchieana* were shown to them to help us to locate the manufacturer, middlemen, and *Nannorrhops ritchieana* business community. We then approached the middlemen who informed us about the manufacturers and markets where these handicrafts, goods and utensils were sold. The name, education level, location and profession of each applicant were recorded. Questions related to the season of leaves collection, people involved in the collection, types of handicrafts, threats to the species, goods, utensils, prices, and ways of transportation, etc. were asked and noted. Market values and information about cultural importance and manufacturing techniques were also solicited. Interviews of focus group 1 were mainly related to the cultivation, culture, and economics of the *Nannorrhops ritchieana*. We then approached focus group 2 which included the local shopkeepers of the handicrafts and business community related to *Nannorrhops ritchieana* handicrafts in the urban regions. Different markets were visited where 19 shopkeepers (all male) and *Nannorrhops ritchieana* handicraft traders were interviewed concerning prices, priorities, highly sold products, the best season for sale, types of customers, supply, demand, and future resilience in the marketing of the *Nannorrhops ritchieana*. All the regions which were included in this study, are the residing places for unique ethnic groups of both the focus groups and hence the word ethnic group has been used during questionnaire surveys.

Table 3.2.2 Frequencies of Age groups and literacy level of the Informants in the study area

Age groups	No. of respondents	percentage
12-24	5	6.5
25-36	9	11.7
37-48	17	22
49-60	20	25.98
61-72	16	20.76
72+	10	12.98

Table 3.2.3 Frequencies of Age groups and literacy level of the informants in the study area

Literacy level	No. of respondents	Percentage
Illiterate	33	42.85
Primary	26	33.77
Middle	10	12.99
Secondary	6	7.79
University	2	2.60

3.2.3 Data analyses

Data were analyzed qualitatively and quantitatively for having a pattern of usage among various ethnic groups from both focus groups. Uses of different items prepared from *Nannorrhops ritchieana* in the areas from where it was collected and documented during the market survey, were arranged into use categories and subcategories (Araújo *et al*., 2016; Macía, 2004). Details of these categories are specified in Table (3.2.3).

Data sets of 37 different items recorded among 22 categories, from the regions of both focus groups, were analyzed using the heatmaply package in R-programming for checking patterns via heat map clusters following (Camara-Leret *et al*., 2017). Availability (1) and non-availability (0) of specific use data were used for heatmap cluster formation. Such analyses were carried out with a hypothesis that use categories change with changes in indigenous communities as well as rural-urban lifestyles.

3.2.4 Relative frequency of citation (RFC)

The ethnoecological data documented during questionnaire surveys were quantitatively analyzed via the relative frequency citation (RFC) index to show the local importance of each handicraft (Vitalini *et al*., 2013).

$$\mathrm{RFC} = \frac{\mathrm{FC}}{\mathrm{N}} \ (0 < \mathrm{RFC} < 1)$$

Where FC is the number of informants mentioning a particular handicraft while N represents the total number of informants participating in the survey.

3.3 RESULTS

3.3.1 Preliminary information about the respondents

Preliminary respondent data confirmed local farmers, handicraft experts' middlemen, sellers and shopkeepers who participated in the questionnaire survey. The largest proportion of the informants were elderly, older than 49 years (Table 3.2.2). Among the 77 informants, 33% were illiterate and 26% were in primary education, which shows the unavailability of education facilities in these regions (Table 3.2.3). These preliminary results also authentically showed that indigenous knowledge about the items prepared from *Nannorrhops ritchieana* is common and very popular among focus group 1 but is decreasing rapidly among youngsters. Moreover, a strong decline has been observed in marketing based on interviews of focus group 2 due to the availability of the synthetic alternates of the *Nannorrhops ritchieana* handicrafts, though of very low quality and durability.

3.3.2 Nannorrhops ritchieana handicrafts and their socioeconomic importance

Each item processed from the leaves of *Nannorrhops ritchieana* was notable but few of them due to their high demand provided maximum cash and hence shared in the economy of many of these areas. The highest use preferences were recorded for hotpots followed by salt pots and mats, brooms, hand fans, cultural shoes, baskets, etc. Hotpots were used in day-to-day life (Figure 3.3.1a). Every house kept hotpots for pieces of bread to remain fresh and warm for a long time after being cooked. Salt pots were used for salt packing and keeping in kitchens (Figure 3.3.1b). Mats of different sizes were of wide use and importance for many purposes e.g., prayer gathering, drying grains, guest sittings, sleeping, poultry cages, and truck (Figure 3.3.1c, d, e, f). The demand for sleeping mats increased in the summer season as these had a cooling effect due to their insulating and hydrophilic nature. These mats did not absorb heat as compared to mattresses made up of cotton and other raw materials. Brooms of different sizes were used to clean houses, shops, and other places (Figure 3.3.1g, h) Hand fans locally known as Babozay were a unique sort of fan used for aeration by the indigenous people where they cannot offer electric fans or during the absence of electricity (Figure3.3.1 i). Traditional shoes made up of *Nannorrhops ritchieana* leaves were used mostly in spiritual and cultural ceremonies and gatherings (Figure 3.3.1j). Baskets of four different types and sizes, i.e., large, middle, large flat and very small (Figure 3.3.1 k, l, m, n) were used in restaurants and hotels. A cage to cover livestock mouths locally known as Bhoka was used to prevent cattle from eating harmful things or fodder during illness or ploughing in cropped fields (Figure 3.3.1 o). Bags for collecting fodder locally known as Kwaray were used by shepherds and farmers to collect grass during and at the end of the summer season (Figure 3.3.1 p). Bags were used for picking fruits from orchard trees and were locally known as Pachai (Figure 3.3.1 q). Similarly, special Pachai was used for packing sweets, especially a sweet known locally as Amrassa. Lund Khuar City in Mardan, Warrai in Dir upper and Batkhela Malakand were popular cities for these kinds of special sweets (Amrassi). Hats made of *Nannorrhops ritchieana* leaves were worn during prayers in the mosques or used by laborers to protect the head from the blazing rays of the sun (Figure 3.3.1 r). Grain boxes were used for the storage of grains and flour which was used to keep grains protected from moisture, heat as well as insects (Figure 3.1 s). Ropes for cots, Katkay were prepared from the fresh and dried leaves of *Nannorrhops* locally termed as Bonr or Rasai that was used to form bedsteads (Figure 3.1 t, u, v) chairs or tying of other things. These ropes were also used to pull water from the wells via wheels.

3.3.3 Preparation of fibers from leaves

The preparation of fibers from *Nannorrhops ritchieana* leaves was tough and laborious work. Leaves were soaked in water for 20 to 30 days till they had softened and then hammered with a wooden hammer to remove the peel. The remaining bulks of the leaves were then washed with water and rinsed into fiber and dried again. The dried fibers were then utilized for shoes, ropes and various other handicrafts formation.

3.3.4 Dyeing of Nannorrhops ritchieana leaves and fibers

Different dyes such as green, blue, red, black, pink, and yellow were used to colour leaves and fibers of the *Nannorrhops ritchieana* for ornamental purposes. Dyes were mixed with freshly boiled water. It was then continuously stirred with the help of a wooden stick till the colours on the fibers had been absorbed deeply. The leaves and fibers were washed with tap water after 20 to 30 minutes of drying. The washed leaves were hung on ropes or scattered in the sand to dry. The dyed dried leaves were then used in combination with normal leaves for decoration in various handicrafts.

Table 3.3.1 Various handicrafts formed from *Nannorrhops ritchieana* and their uses

S. No	English name of Handicrafts	Pashto name of Handicrafts	Part used	RFC	Uses	Market Price
1	Hot pot	Petwar	Leaves	0.76	Used to keep bread, Toast, etc. warm	230
2	Salt pot	Malge wala Lokhay	Leaves	0.65	Used as a pot for salt	70
3	Mat for beds	Kat pozakay (1x2m)	Leaves	0.60	Used as a mattress mostly during the summer season due to its cooling effect	100
4	Mat for poultry cage	Panjre da para pozakay (1x1m)	Leaves	0.57	Used in poultry cages to stop grains from falling on the earth	100
5	Mat for vehicles	Garo wala chetai (1.5x1m)	Leaves	0.57	Mostly the conductors and drivers of heavy vehicles or trucks covering long distances use to sleep on the ground rest, coolness and sleep on these mats	240
6	Mat for grains	Dano wala Chetai (4x4m)	Leaves	0.49	Used to dry cereal grains	190
7	Mat for guests	Chetai melmano da para (2x3m)	Leaves	0.44	Used for setting the guest	250
8	Prayer mat for one individual	Jai Namaz, Musalla	Leaves	0.41	Used for the prayer of a single person	1700
9	Prayer mat for a group of individuals	Saf/ Purr (1x8m)	Leaves	0.41	Used for prayer of many peoples	1200

10	Small broom	Wara Jaro/Jarogai	Leaves	0.38	Usedto clean shops or rooms	300
11	Large broom	Ghata Jaro/ Jaro	Leaves	0.38	Used to clean large houses and lawns	1500
13	Hand fan	Babozay	Leaves	0.36	Used to run the current of air	550
14	Shoes for common uses	Saflai	Leaves	0.33	Shoes used in cultural gatherings and recreational activities	850
15	Shoes for ice skiing	Wawro safely	Leaves	0.19	Used in the past to walk on ice	1200
16	Large basket	Tokra	Leaves	0.21	Used for shipping different items from one place to another	280
17	Middle-size basket	Shkarai	Leaves	0.30	Used to keep bread	120
18	Large-size flat basket	Shkor	Leaves	0.31	Used to remove husks from grains	100
19	Baskets used in hotels	Shkor hotel wala	Leaves	0.27	Used in hotels to keep bread	90
20	Cover for animal mouth	Koaray da janwaro da khole da para/ Bhoka	Leaves	0.22	Used to cover the mouth of newborn or unhealthy cattle to stop them from eating harmful substances	110
21	Bags for packing grasses	Kwaray	Leaves	0.24	Used to pack fodder for cattle. It is also used by street sellers for packing steel, silver and plastic pots.	150
22	Packing bags for sweets	Pachai	Leaves	0.23	Used for packing bakeries and brown sugar	720

23	Hat	Topay	Leaves	0.21	Used to protect the human head from the blazing heat	400
24	Grains bin	Tatra or Kando	Leaves	0.13	Used to store grains	350
25	Box	Petai	Leaves	0.15	Used to store grains or floor	100
26	Ropes	Bonr	Leaves	0.19	Used to form bedsteads (Figure. 3.3.1v), or for tying other things	450
27	One seater small bed	Katkay	Leaves	0.28	Used for setting a single person	550
28	Rope	Lange wala rasai	Leaves	0.05	Used to form a bed.	1000
29	Rope for well	Kohi wala rasai	Leaves	0.08	Used to take water out from well via wheel	230
30	Ornamental	Gamle wala plant		0.02	Used for aesthetic and recreational beauty	340
31	Donkey Kage	Lad	Leaves	0.06	Used to carry weights on a donkey from one place to another	550
32	Fuel	Khashak/ Largay	Leaves+ stem sheaths	0.09	Dry leaves stem sheaths and roots were used for fuel purposes	450
33	Toothbrush	Miswak	Petiole	0.13	The petiole of the leaf is used as a toothbrush	**Consu mers**
34	Fruit, New shoot	Patawa,	Fruit, Fresh shoot	0.06	Fruits and young shoots used for nutritional purposes	230

35	Marbles	Belouree	Seeds	0.14	In some areas kids played marble games using its hard-round seeds, the game is locally known as Belouree	70
36	Roofs or ceiling	Sapar/ Chappar	Leaves	0.03	In some areas, the leaves are used for roofing or thatching	100
37	Medicinal uses	Tibi estimal/ Dawai	Leaves	0.76	Fresh leaf extract is used for stomach problems	100
38	Fodder	Gayah/ Wakha	Leaves	0.65	Young leaves are grazed by animals and were also used as fresh powder	240
39	Cages	Panjra	Leaves	0.60	Used to keep rare birds like Chukar, Parrot, Mayanas, etc.	190

3.3.5 Role of Nannorrhops ritchieana in cultural services and ecotourism

People of Pakistan in general and tribal are well known for their hospitality and other cultural norms. Hujra and Betak (guest house) were significant entities in these cultures. Local communities f in the studied regions kept different items made from this in their guest houses which were used in one way or the other as various cultural obligations. They form cots, stools, and mats of *Nannorrhops* leaves which were essential contributions to the Hujra and Betak cultures. Hujra and Betak systems have beds locally known as "Khats", sofas known as Khatkey, mats for prayers, mats for settings, mats for sleeping, hand fans, etc. Guests are offered and served in Hujra or Betak traditionally which contributes to ecotourism in these areas. Many people from urban regions used to visit rural areas to see these cultural ecosystems which are present in the form of these things.

Tourists visit colder areas of the country such as Swat, Muree, Abbottabad, Ayubia, Quetta, Ziarat and others to enjoy such cultures during the summer season. On the way to these regions there existed some markets trading cultural items. The charming beauty of these handicrafts attracted tourists to buy them. *Nannorrhops ritchieana* displayed outside in pots enhances the beauty of houses, hotels, and restaurants. It also increased the aesthetic attraction of road landscapes due to its silver-green color. In summary, *Nannorrhops ritchieana* has an outstanding role in providing different ecosystem services, ecotourism, hospitality, and traditions.

Figure 3.3.1 *Nannorrhops ritchieana* handicrafts, goods and utensils

(a) Hot pot (b) Salt pot (c) Mat for beds (d) Mat for vehicles (e) Prayer mat for one individual (f) Prayer mat for a group of individuals (g) Small broom (h) Large broom (i)

Hand fan (j) Shoes for common use (k) Large basket (l) Middle size basket (m) Large size flat basket (n) Basket used in hotels (o) Cover for animal mouth (p) Bags for packing grasses (q) Packing bags for sweets (r) Hat (s) Grains bin (t) Ropes (u) One seater small bed (v) Cot or bedstead (w) Ornamental plant (x) Lad (y) Fuel (z) Toothbrushes (aa) Fruit (ab) Seeds used as marbles (ac) Horse sculpture formed by an old artisan (ad) An old artisan weaving ropes from *Nannorrhops ritchieana* leaves

3.3.6 Heatmap clustering approach for the classification of different regions

Ethnocultural uses and regions where it was used are clumped into two clusters which can be observed in the heat map (Figure 3.3.2). Various tribes (as mentioned in the second chapter) inhabited various areas where *Nannorrhops ritchieana* grows or was sold in markets. A heatmap dendrogram was constructed based on the correlation among regions in terms of different handicrafts usages showing the distribution of various uses among the above-mentioned ethnic groups living in different areas and the similarity in the *Nannorrhops ritchieana* uses (Figure 3.3.2).

3.3.6.1 Cluster 01 northern and central parts of Khyber Pakhtunkhwa

Cluster one comprised Mansehra, Abbottabad, Haripur, Mingora Swat, Timergara Dir Lower, Qissa Khwani bazar Peshawar and Pir Baba Buner. These regions were in the northern and central parts of Khyber Pakhtunkhwa. Mansehra, Abbottabad and Haripur are located in the Lesser Himalayas. People of these areas had the same Hindku language and culture. We encountered very few populations of *Nannorrhops ritchieana* in these regions. Various types of handicrafts were imported from other regions of the province. Moreover, Mingora Swat and Pir Baba Buner Timergara Dir Lower are in the Hindukush range. These were among the colder areas of the country also known as provincially administrated tribal areas (PATA) *Nannorrhops ritchieana* did not grow here and hence people imported it from the adjacent areas where was abundant. On the other hand, Qissa Khwani Bazar Peshawar is an important historical centre of the metropolitan city of Peshawar. In these regions, *Nannorrhops ritchieana* was not distributed but these regions were located on the border to other regions where the species was extensively distributed and used for different types of handicrafts. They imported various types of *Nannorrhops ritchieana* handicrafts such as baskets, hand fans, brooms, ropes, etc.

3.3.6.2 Cluster 02 presenting the border regions of Khyber Pakhtunkhwa

This cluster was comprised of six sites i.e., Jhandai Mardan, Lonkhwar Mardan, Khar Bajaur, Kohat, Dera Ismail Khan and Bannu are the areas of Lower Khyber Pakhtunkhwa where different Pashtoon's communities lived. In Khar Bajaur, Kohat, Dera Ismail Khan and Bannu *Nannorrhops ritchieana* was cultivated to fulfill different requirements. Moreover, Jhandai Mardan, Lonkhwar Mardan and Charsadda were important marketing regions for *Nannorrhops ritchieana* handicrafts. They imported *Nannorrhops ritchieana* leaves from different regions of Bajaur, Mohamnd, Kohat division and Kurram Valley. These regions were clumped into one cluster with the species-growing regions, because of the similarities and priorities of different handicrafts. It also showed that these communities have the same cultural values and hence favoured the same utensils and goods irrespective of living in different provinces. Moreover, these are the areas where *Nannorrhops ritchieana* grows or once had been grown in the recent past.

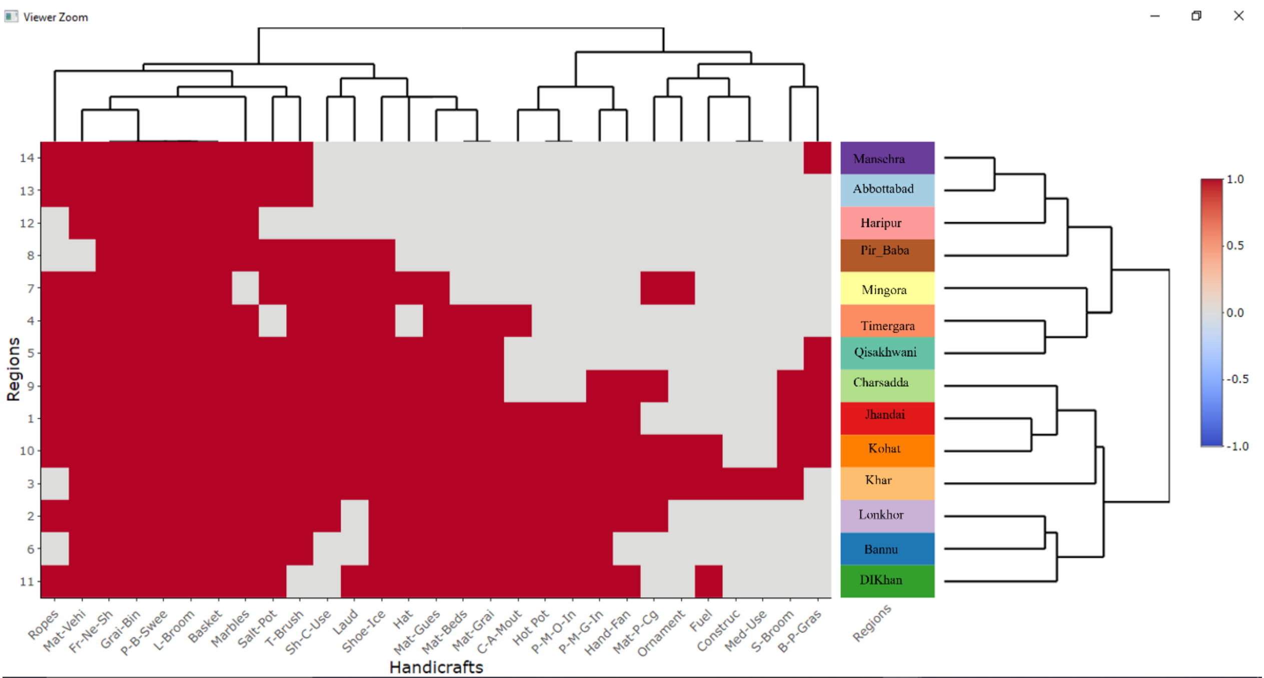


Figure. 3.3.2 Heatmap showing cultural groups using *Nannorrhops ritchieana* plant in the study area

3.4 DISCUSSION

We show close ties between the cultural services provided by *Nannorrhops ritchieana* and human well-being in Pakistan. Indigenous communities in the country possess knowledge about the ecosystem services of this enigmatic palm species. There is a considerable variation from area to area and community to community in items processed from *Nannorrhops ritchieana* leaves. We show that *Nannorrhops ritchieana* facilitates a wide range of people as their livelihood resource in Pakistan. As such, it provides raw materials for a variety of handicrafts used in fodder, food, fruit, fuel, medicines, toys, and several other cottage industries in traditional communities. In the literature (Thomas *et al*., 2012) it is reported that the *Nannorrhops ritchieana* is a source of fibers for weaving various utensils and ropes for making mats, fences, houses, roofs, hand fans, baskets, brooms, trays, prayer mats of various sizes grain bins, hot pots, hats and cultural sandals. We confirm a few of the results of (Goodman and Ghafoor, 1992). Many similarities in our reported uses may be due to the deep relationship between various ethnic communities living in Khyber Pakhtunkhwa who have shared cultural values and norms. On the other hand, according to (Panhwar and Abro, 2007) reddish moss-like wool of the petioles of *Nannorrhops* is used as tinder. The seeds are utilized for making rosaries. In the current study, we have not had any similar recorded use by locals. Furthermore, the high rate of exploitation of the *Nannorrhops ritchieana* in the 20th century has decreased the provisioning of cultural services from this palm. In Pakistan local inhabitants particularly, the older generation tend to live in mountainous valleys due to the availability of natural ecosystem services which they benefit from by possessing indigenous ethnoecological knowledge. The younger generation, however, tends to migrate and live in cities in search of education, health and other facilities (Khan *et al*., 2013).

Cluster and Two-Way cluster dendrograms show the association and distribution of uses in different zones of various cultural groups (Figure 3.3.2). Its usages also show that the people of the northwestern part of the country had more knowledge about the uses of *Nannorrhops ritchieana* as compared to the urban areas. Some authors deduced this in the same manner (Fandohan *et al*., 2010; Koura *et al*., 2011; Sop *et al*., 2012). Another significant finding of the current study is the clear link between the inhabitants' perception of various provisioning services and their resident municipalities. The maximum uses of handicrafts were in rural areas as compared to urban ones. This explains that in rural areas the inhabitants directly collect the plant species from the wild to process several handicrafts. Also, in urban areas, people can reach and afford easily for various types of artificial handicrafts. The previously available literature on *Nannorrhops ritchieana* shows that it is a plant species used for various purposes due to which it is known by different vernacular names in various regions of cultures in Pakistan as well as in other parts of the world. These names vary in different regions and communities. In Arabic it is called

Ghadaf, or Saf (Mosti *et al*., 2006), English, Mazri Palm (Gibbons and Spanner, 1995) Merez, Afghani Pashto (Sabet, 1994), Patha, Balochistani Pashto (Ajaib *et al*., 2013), Mazri in Saraiki (Marwat *et al*., 2011), Purk, Persian (Khodashenas *et al*., 2016), Daz, Balochi (Panhwar and Abro, 2007), Mezaray, Malakand, Swat, Dir, Bajaur, Mardan (Murad *et al*., 2011), Mazara, FR Bannu (Adnan *et al*., 2014) Mazarai, South Waziristan (Aziz *et al*., 2016), The palm family is one of the richest family in term of fiber producing plants. It contributes tremendously to cultural utilization throughout the globe. Researchers reported a variety of uses of different taxa in different regions for example (Araújo *et al*., 2016) reported that the natives of Tucurui Lake in the eastern Amazon use *Attalea speciosa* (Babassu) for utensils, tools, human food, animal fodder, construction, fuel, medicines, cultural and other uses. Uses of *Attalea speciosa* reflect similarities to our findings of *Nannorrhops ritchieana* in the current study. Ethnoecological studies of *Braheae dulcis* show its use for 20 different purposes. Leaves have been mainly harvested for eight decades. Religious uses and handicraft preparations are the two main categories of this species' utilization (Pulido and Coronel-Ortega, 2015). *Afzelia africana* of the legume family is also an important species used for various cultural purposes. The local communities of Burkina Faso use this species as fodder, medical plant, food, and supply as raw material for carpentry and construction. The ethnobotanical and economic value of *Ravenala madagascariensis* in east Madagascar is studied by (Rakotoarivelo *et al*., 2014). According to them the species is of immense importance for the indigenous communities. The trunk, heart, leaves, and petioles of that species are the highly exploited parts. They use it as utensils and tools, human food and for construction purposes. Zambrana *et al* (2007) documented the context of the use of *Euterpe precatoria* and *Euterpe oleracea* in Bolivia and Peru. The inhabitants of Peru use fruits and hearts of *Euterpe precatoria* more than the inhabitants of Bolivia for commercial and human food purposes which shows similarity to the uses of *Nannorrhops ritchieana*.

3.4.1 Advantages of using Nannorrhops ritchieana products

Nannorrhops ritchieana has great aesthetic value and can be recommended to be planted along the main highways in Pakistan and adjacent countries with similar climates for beautification and combating of pollution along roadsides. It can also increase the production of raw materials for a variety of potential handicrafts. Products formed from the leaves of *Nannorrhops ritchieana* have advantages over artificial fibers for many reasons.

Natural fibers are environmentally friendly, non-toxic, biodegradable, easily available, compostable, long-lasting and heat resistant. These products have a great capacity for insulation against sound and heat waves as well as water. Artificial fibers have a much more abrasive nature as compared to natural fibers and take more time during processing techniques and recycling. Fibers of *Nannorrhops ritchieana* have a longer range of elasticity, high toughness, and biodegradable and environment-friendly nature.

3.5 CONCLUSIONS

Nannorrhops ritchieana has an outstanding role in the livelihood of the indigenous communities living in different parts of Pakistan's Khyber Pakhtunkhwa province. *Nannorrhops ritchieana* has been significantly used and important in the life of especially rural as well as urban populations in the province. The cultural uses of the species vary from place to place based on the cultural history and traditional knowledge of the communities. Indigenous communities in *Nannorrhops ritchieana* growing region retain important traditional knowledge about handicraft preparation and its strong associations with the culture and tradition of the communities. *Nannorrhops ritchieana* is an important source of livelihood for local communities in dry habitats of the province from the coastal areas of D I Khan to the district of Bajaur. The collection and processing practices of *Nannorrhops ritchieana* leaves have decreased in recent eras due to modernization and development in science and technology, which will be considered a serious threat to the conservation and diversification of *Nannorrhops ritchieana* handicrafts. We believe that this study will serve as a baseline to conserve this traditional knowledge about handicrafts prepared from *Nannorrhops ritchieana*. These findings could be of interest to scholars and handicraft experts all over the glob

CHAPTER 4

Population ecology of *Nannorrhops ritchieana* (Griff.) Aitch. in Khyber Pakhtunkhwa, Pakistan

4.1 INTRODUCTION

There is no doubt that the earth is under the control of one keystone species called *Homo sapiens* (Kueffer, 2022). The population of *Homo sapiens* increases at an alarming speed and now hits the figure of eight billion (Adam, 2022). The incessant upsurge in population causes urban expansion, infrastructure, road construction, mining (Ahamd *et al*., 2022) and the conversion of forest land into buildings and agricultural fields (Abdullah *et al*., 2021). In the conversion of forest land, some species face the problem of extinction (Dalrymple *et al*., 2023). Moreover, some species are heading to extinction due to overexploitation (Zehra *et al*., 2023). In the current scenario of the Anthropocene understanding the ecology of plant populations is mandatory for future conservation (Heywood, 2017). Population density, dispersal, distribution pattern, age structure, natality, mortality, and the factors that affect its population are the key parameters to be focused on while assessing the species' population ecology (Conquet *et al*., 2023), particularly those who face the problem of overexploitation. *Nannorrhops ritchieana* is among those who face the problem of overexploitation (Abdullah *et al*., 2019). It is an important palm species of the Coryphoidae subfamily of Arecaceae. It is distributed in Pakistan, Afghanistan, Iran, Oman and Saudi Arabia (Abdullah *et al*., 2020). In Pakistan, it is distributed in different regions from the Arabian coast to the Himalayan mountains. Seed is the main source of propagation, mainly dispersed by humans, birds and cattle. In different regions animals feed on their seeds which facilitates its dispersion (Sayedi *et al*., 2022), therefore it has a sporadic type of distribution across different regions. Sometimes, it occurs in the form of dense patches in the Pashto language called "Tal" but its overexploitation leads to a drastic decrease in its population. This dramatic decrease in its population has happened over the past 100 years or maybe more. During our fieldwork, we asked an 87-year-old man "Niazbeen Mian" belonging to the Utmankhel- Aseel tribe in village Targhao (he is the chieftain/Malak of the Mian tribe in the region) about the past and present population status of *Nannorrhops ritchieana* in the region. He presented his view in these words: “In our time when we were children, we used to collect Mezari from the surrounding slopes for fuel purposes. All slopes were full of old individuals of Mezari. Then with an increase in opium demand and prices, we convert the Mezari slopes into fields. Now we only have Mezari plants on field banks they are the remains of that old plants".

At the start of the 20^{th} century conversion of *Nannorrhops ritchieana* habitats into agricultural fields was at its peak. In the mid of century, when Pakistan was just seven years old, the country passed an act for its conservation called the Kohat Mazri control act of 1953 (Latif *et al*., 2004; Khan 2012; Naureen, 2009). The act was first devised for the Kohat division which then covered the whole province of Khyber Pakhtunkhwa (Abdullah *et al*., 2019) and currently, it is a section in the Khyber Pakhtunkhwa Forest Ordinance 2002 (https://kpcode.kp.gov.pk/homepage/lawDetails/1221). The main objective of the act was to protect, preserve and propagate the species in the region. In the act, the conversion of *Nannorrhops ritchieana* forest into agricultural fields was banned through law and rules. In addition to overexploitation, the Indian crested porcupine (*Hytrix indica*) and the black bear uproot the species and cause a considerable loss to its population. *Nannorrhops ritchieana* roots are the favorite food and feast of the porcupine population (Abdullah *et al*., 2019; Abdullah *et al*., 2022). It was also recorded that with the decline in the population of *Nannorrhops ritchieana* the porcupine population is also decreasing in different regions of the study area (Abdullah, 2019). To safeguard *Nannorrhops ritchieana* and the porcupine population in the region proper evaluations are needed. Here, we for the first-time focus on the population assessment of *Nannorrhops ritchieana* across the province of Khyber Pakhtunkhwa. We hypothesize that the number of seedlings is less than the juvenile and young-age plants which may be challenging and detrimental to its future sustainable life. Based on the results of our current evaluations of *Nannorrhops ritchieana* we present another hypothesis that inflorescence size, fruit, number, fruit and seed size are controlled by plant age. The objectives of this research were (i) quantification of *Nannorrhops ritchieana* individuals in different age classes across different populations. (ii) to determine the effect of different age classes on the inflorescence size, fruit number, fruit size and seed size (3) to document different threats to the species across the studied region.

4.2 MATERIALS AND METHODS

4.2.1 Population data

We quantified 63 *Nannorrhops ritchieana* populations further comprising 508 plots of 10x10 meter square size. A total of 16 plots within two populations were located at zone 01 eastern wet mountains, 162 plots at zone 02 northern dry mountains, within 20 populations, 222 plots in zone 03 western dry mountains within 30 populations and 107 plots within 10 populations at Zone 04 Sulaiman Piedmont. Within each plot, we counted all *Nannorrhops ritchieana* individuals and measured their cover. Species IVI in each population was also calculated. It is the sum of the relative frequency, relative cover and relative data of the species divided by 3 (Anwar *et al*., 2019). We recorded stump numbers in each plot. Plant height was measured manually using measuring tape. We also documented the *Nannorrhops ritchieana* seedling number and the threats they face such as forest fire, anthropogenic pressure, uprooting by animals (porcupine spines), road construction, conversion to agricultural fields, soil erosion, and soil mining, etc. various slopes on which species populations are located were also documented. Each individual of *Nannorrhops ritchieana* inventoried in the studied region was classified into one of five classes modified from the protocol provided by (Portela and Santos, 2014; Quek *et al*., 2020). (1) Seedling; an individual with an undifferentiated stem from other palms. *Nannorrhops ritchieana* seedling is difficult to be differentiated in early years from other palm species. (2) juvenile; an individual with differentiated leaves but no records of inflorescence (3) Young; a mature individual with a height of 100 cm. Intermediate individuals; mature plants with up to 20°Cm stem height. Old; mature individuals with heights over 200 cm.

4.2.2 Fruit ecology

We recorded 51 inflorescences from different populations. Inflorescence with mature and immature fruits was collected from different regions. Inflorescences with immature fruits were gathered to minimize error chances in fruit counts due to frugivory and wind. We measured inflorescence length, fruit number, fruit size and seed size to determine the impact of plant age. We evaluated Sixty-three different populations comprising 508 plots of *Nannorrhops ritchieana*. We visited all these places consecutively for 3 years. We categorized all plants into three groups. (1) Newly mature plants (2) Middle-age plants (3) Old-age plants. We quantify inflorescence size, number of fruits, fruit diameter, and seed diameter in old and young plants across the same and different populations. We located inflorescence and seeds in 19 different populations and 51 plots.

4.2.3 Data analysis

We put the collected data on MS Excel sheets and visualized using different types of visualization such as line graph and stack chart methods. We determined the correlation among different variables of fruit ecology with stem height to understand the impact of stem height on them and then we visualized them further with regression models. The regression models using the ggplot2 package in R-programming were used to determine the relationship between plant age (assumed from plant height data) and plant reproductive ecology using inflorescence length, fruit number, fruit size, and seed size data. The inflorescence length, fruit number, fruit size, and seed size were used as response variables while plant height or age was considered as an explanatory variable.

Figure. 4. 2.1 Young individuals of *Nannorrhops ritchieana* in Kurram Valley

Figure. 4. 2.2 Medium-aged individuals of *Nannorrhops ritchieana* in D I Khan Abdulkhel

Figure 4.2.3 Old-aged individuals of *Nannorrhops ritchieana* in Mian Umar Baba Bajaur

4.3 RESULTS

4.3.1 Age Structure

Four climatic zones across the province of Khyber Pakhtunkhwa were explored. A total of 2269 *Nannorrhops ritchieana* individuals were recorded with 110 seedlings, 1241 juvenile, 630 young plants, 259 mature plants and 29 old plants individuals. Zone wise in the eastern wet mountain zone (EWMZ) two seedlings, 15 juveniles, 23 young plants, 28 mature plants and only three individuals in the old class were recorded. In the northern dry mountain zone (NDMZ) 14 seedlings, 295 juveniles, 143 young plants, 62 mature plants and 11 old individuals were reported. In the western dry mountain zone (WDMZ) 91 seedlings, 665 juveniles, 295 young plants, 137 mature plants and 13 old individual was reported while in the Sulaiman Piedmont zone (SPMZ) three seedlings, 266 juveniles, 169 young plants, 32 mature plants and only two old individual was reported (Figure, 4.3.1).

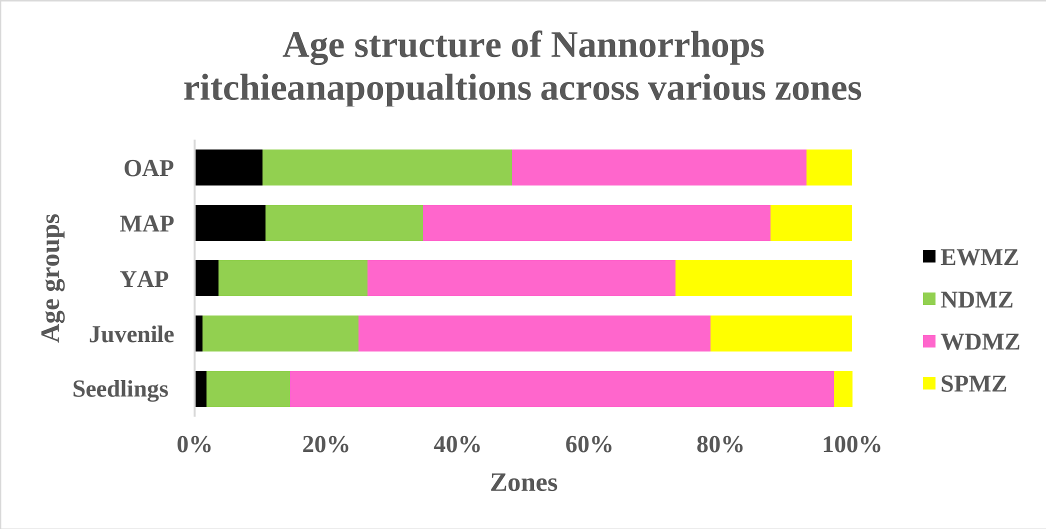
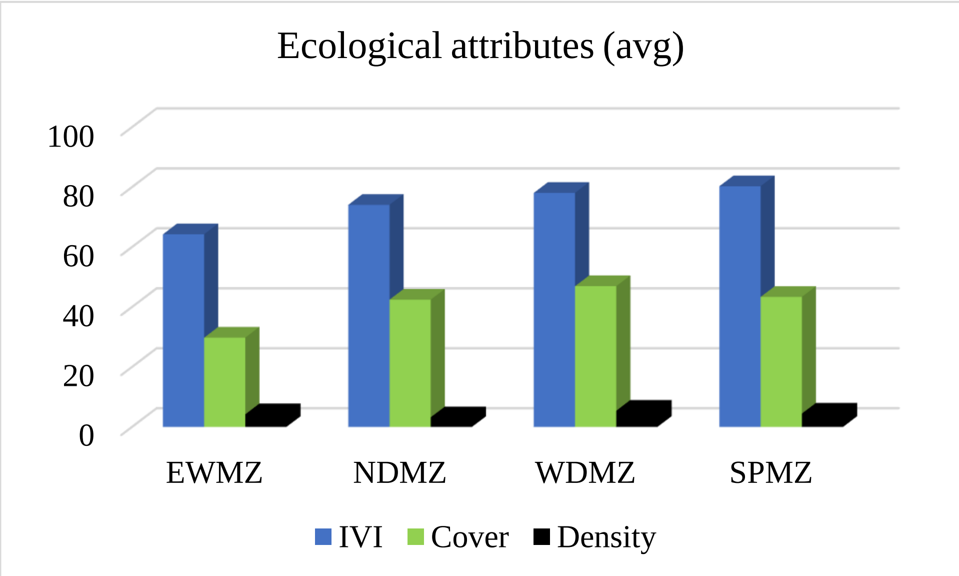


Figure 4.3.1 The age structure of individuals of *Nannorrhops ritchieana* in four different zones in Khyber Pakhtunkhwa

4.3.2 Ecological Attributes across different zones

Ecological attributes data across different zones show that the average density recorded for EWMZ was 4.23, NDMZ, 3.21, WDMZ 4.48 and SPMZ 4.46. On the other hand, the average cover for EWMZ was 29.78, NDMZ 42.45, WDMZ 40.05 and SPMZ 43.4 % recorded. Moreover, the average IVI in EWMZ was 64.24, NDMZ, 74.08, WDMZ 76.38 and SPMZ 80.29 (Figure, 4.3.2)



Figure, 4.3.2, Ecological attributes of *Nannorrhops ritchieana* across different zones of Khyber Pakhtunkhwa

4.3.3 Natality

We recorded natality by counting the number of seedlings. Unfortunately, the number of seedlings was lower than the numbers in other age classes. A total of 119 seedlings were recorded across the studied region. The number of seedlings in EWMZ was only two, NDMZ, 14, WDMZ 91 and SPMZ only three (Figure 4.3.3).

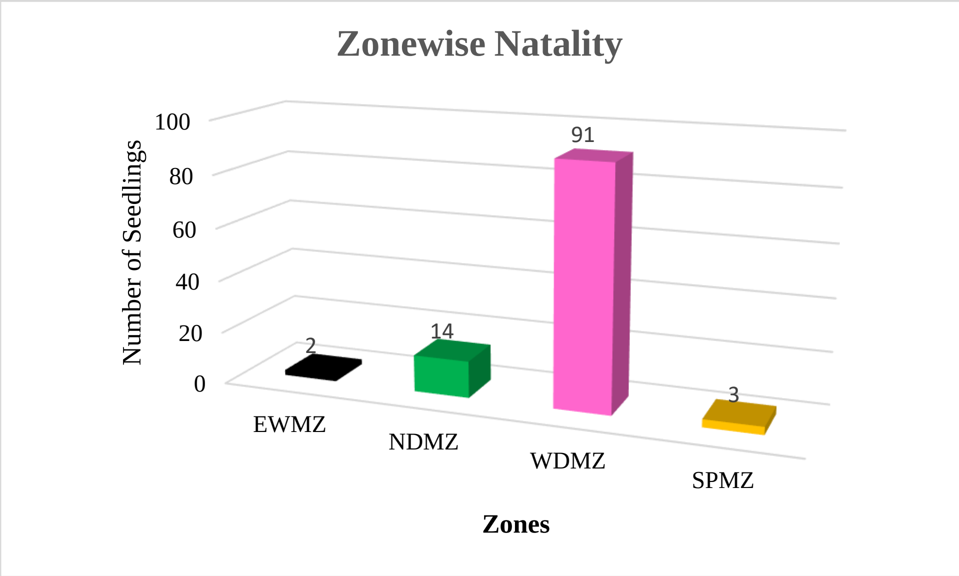


Figure 4.3.3 *Nannorrhops ritchieana* natality across different zones of Khyber Pakhtunkhwa

4.3.4 Mortality

We recorded the *Nannorrhops ritchieana* mortality by counting the number of plants that died due to human pressure or natural disasters. The uprooting by porcupines was also a serious threat. They uprooted many individuals across different zones. A total of 172 stumps were recorded across the studied region. The number of stumps in EWMZ was 17, NDMZ, 22, WDMZ 69 and SPMZ 65 (Figure 4.3.4).

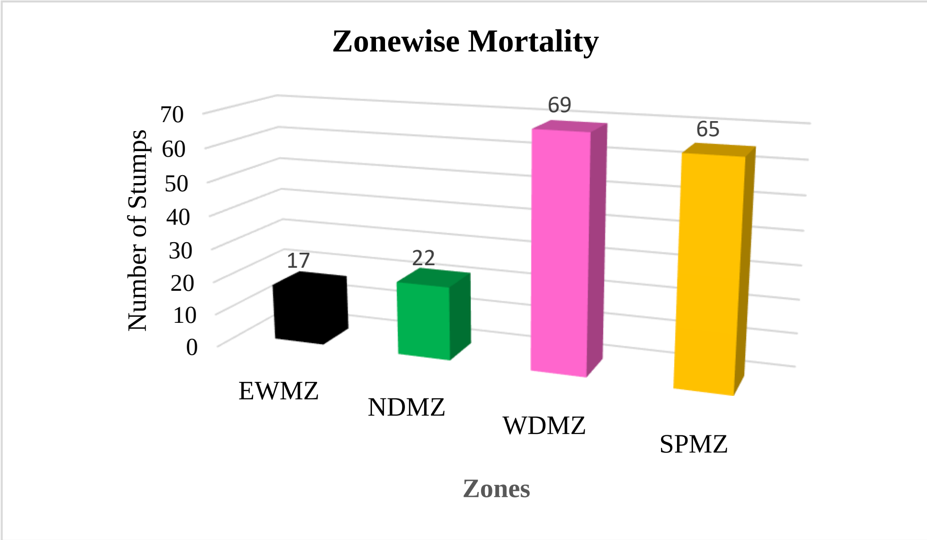


Figure 4.3.4 *Nannorrhops ritchieana* natality across different zones of Khyber Pakhtunkhwa

4.3.5 *Impact of palm height on fruiting ecology*

We determined the correlation between palm height and various traits of fruiting ecology. Interestingly all the variables have highly significant correlations (***). An increase in the height of the species has a direct impact on different traits related to the fruit ecology of the species, i.e., inflorescence, fruit number, fruit size and seed size. Inflorescence size, fruit number, and fruit and seed size have their maximum in middle-aged palms, followed by young and then decreases in old plants (Figure 4.3.5).

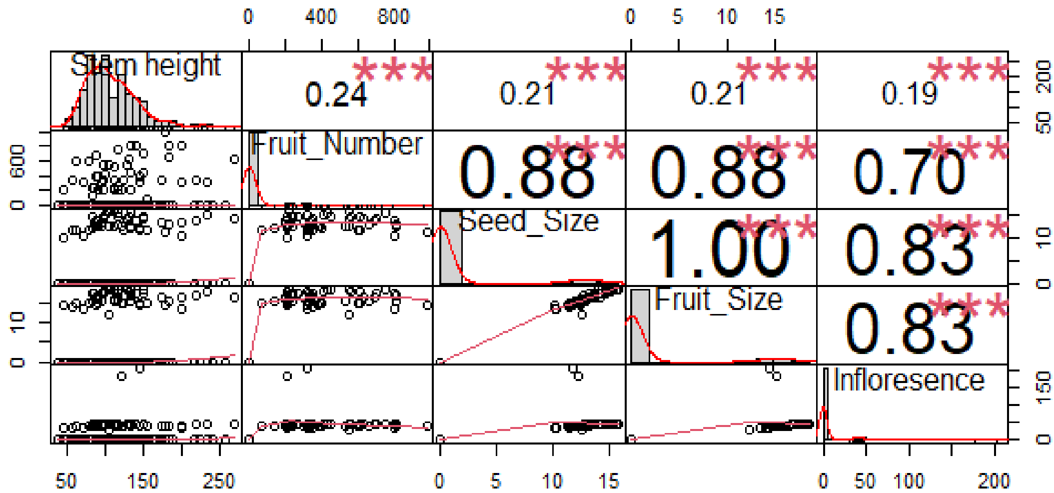


Figure 4.3.5 Correlation analysis of stem height and fruiting ecology in *Nannorrhops ritchieana*

In young plants, the stem height ranged from 45.4–97.71cm, whereas the inflorescence length ranged from 38.60–44.5 cm, fruit number ranged from 317–448, fruit size14.6–16.1mm while seed size was 9.8–13.8. In middle age plants, the stem height ranged from 107.61–193.51 cm, with an inflorescence length of 38.4–206cm, fruit number ranged from 267–981, and fruit size14.3–18.7mm while seed size was 12.2–15.8. In old plants, the stem height ranged from 204.7–323.9cm, whereas the inflorescence length ranged from 31.4–38.1 cm, fruit number ranged from 141–241, and fruit size 12.4–14.3mm while seed size was 10.2–11.9 as shown in Appendix (4.1). Our regression plots show that plant age (height) has a significant impact on inflorescence size, fruit number, fruit size and seed size. Inflorescence size, fruit number, and fruit and seed size have their maximum in middle-aged palms, followed by young and then old plants (Figure 4.3.6).

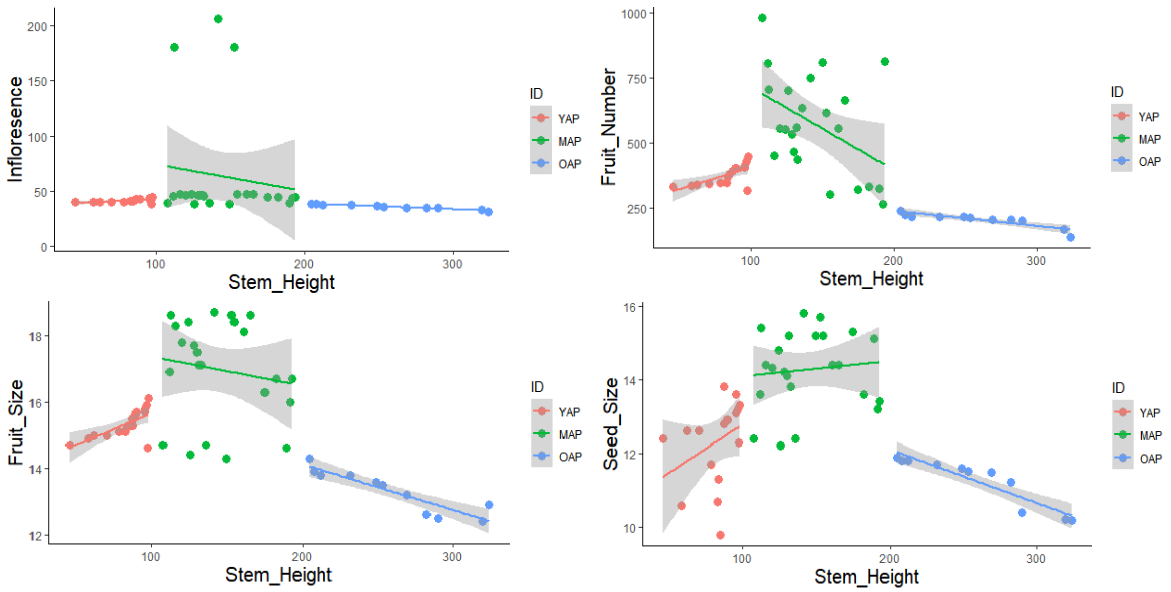


Figure 4.3.6 Regression analysis of stem height and fruiting ecology in *Nannorrhops ritchieana*

4.4 DISCUSSION

In this comprehensive study on the *Nannorrhops ritchieana* populations, we assessed 2269 individuals in which the number of seedlings was less than juvenile, young and mature individuals. The decrease in the number of seedlings shows that it will be difficult for seedlings to cover the gap of other individuals that died and are facing the problem of death due to multiple abiotic and biotic factors. The main problem of seedling conservation is grazing pressure. The seeds are dispersed by birds or by animals (Sayedi *et al*., 2022). After germination, they are mostly eaten by goats and sheep or uprooted by porcupine which is a serious threat not only for seedlings conservation but for other age classes as well. In different regions, the old individuals are conserved by the sanctity of graveyards or places like mountains, i.e., in Sheikh Badin National Park on the top of the hill at the Sheikh Abdul Qadir Jillani Point few *Nannorrhops ritchieana* individuals grow which are considered sacred and the same is true in Mian Umar Baba in district Bajaur where we collected data from a Patch of the species conserved by the people due to their sanctity. Our results are in harmony with that of (Frascaroli *et al*., 2016; Verschuuren, 2010). The juvenile individuals were more abundant than other individuals. In 1980 across different regions of the Western Dry Mountain zone, the species population was devastated by Afghan refugees. To recover from that loss the government dispersed seeds in different regions in their original habitats which are now in the juvenile stage.

Overexploitation is another problem because it provides multiple ecosystem services including cultural, provisioning, regulating and aesthetic since ancient times (Goodman and Ghafoor, 1992; Thomas *et al*., 2012). Among the provisioning services, the most noteworthy are mats, baskets, hot pots, hats, brooms, trays, storage boxes for grain, sandals, cages and many others. Leaves are used in house roofing and thatching and seeds are used for creating rosaries. Dried leaves and petiole are used for fuel purposes. Fruit and the palm heart are used as food (Khan and Shaukat, 2006; Panhawar and Abro 2007; Marwat *et al*., 2011, Abdullah *et al*., 2019, Abdullah *et al.*, 2020, Ali *et al*., 2020; Abdullah *et al.*, 2021, Moricca *et al*., 2021 and Abdullah *et al.*, 2022) from different regions of Pakistan. Collection of leaves in an improper way and time cause serious problems to species conservation and sustainable utilization. The palm heart causes the death of the plant. The children mostly pull the main shoot/ palm hearts to use them as raw food which leads to species mortality. According to our results, a total of 172 stumps were recorded, of which 69 were recorded from WDMZ followed by SPMZ 65 (Figure 4.3.1). In both zones, we recorded various threats but the most prevalent one was road construction and crushed by vehicles. During our survey in WDMZ, the search for oil and gas was continuous while in SPMZ China Pakistan Economic Corridor (CPEC) was under construction where they crushed and uprooted many palm individuals. Similar results have been documented by (Nabi *et al*., 2017; Lashari *et al.*, 2020) who considered CPEC a serious threat to the conservation of biodiversity in northern Pakistan. In EWMZ the species population in Mansehra faces the problem of extinction and very few individuals remain and if the construction activities continue, in a few years the population will be diminished. In NDMZ only 22 stumps were recorded of which most of them were uprooted by porcupines. The people in this zone care for the species for their household usage and some people cultivate the species on the bank of their agricultural fields and hence in this way its density increases. *Nannorrhops ritchieana* density data show that density was higher in WDMZ followed by SPMZ. These zones are considered the original and most suitable habitats for the species. One possible reason for the species' higher density records in WDMZ is the role of law or Mazri Control Act 1953 and favorable climatic conditions while in SPMZ the soil is the almost silty type where the species grows well and establishes dense populations. In EWMZ we reported only two populations dominated by juvenile and young plants. On the other hand, the NDMZ has less population density with higher cover records than other zones with a sporadic type of distribution. Moreover, IVI is the sum of relative density, relative cover, and relative frequency divided by three which vary across different regions. In some cases, plants with lower densities may grow better with high canopy cover than those with higher densities (Feldman *et al*., 2011). The plant height also has a crucial impact on the fruiting ecology of the species (Figure 4.3.7). An increase in the height of the species has a direct impact on different traits related to the fruit ecology of the species, i.e., inflorescence, fruit number, fruit size and seed size. Inflorescence size, fruit number, and fruit and seed size have their maximum in middle-aged palms, followed by young and then decreases in old plants (Figure 4.3.5, Figure 4.3.6). We assume that the species' fruiting ecology might be related to their nutrient acquisition capacity. Plants at a young age might absorb less amount of nutrients than mature plants; they are stout and stronger than old plants because they are at the senescence stage (Figure 4.1, Figure 4.2, Figure 4.3). Therefore, young individuals have a lower output in terms of fruit production than mature and higher than old plants. Studies linking the fruiting ecology of palms with plant age and height are very rare. A study linking the fruiting ecology of *Mauritia flexuosa* in the Peruvian Amazon reported that with the increase in species height, an increase occurs in its fruit number and volume (Romulo *et al*., 2022). Their results contrast with our findings. The difference in the fruiting ecology may be due to variations in geographic locations and associated vegetation. They also mentioned that with the increase in height, the plant captures more and more sunlight which results in higher seed production. But *Nannorrhops ritchieana* is a xeric species that grows in water-scarce areas with the scrubby type of vegetation where they are completely exposed to sunlight. A proper understanding of fruiting ecology concerning plant height across different palm species across different geographic regions is needed to understand the linkage of palm height and its impact on fruiting ecology.

Figure 4.3.7 (a) Young plants fruit (b) Middle-age plants fruit (c) Old plants fruit

4.5 CONCLUSION

Nannorrhops ritchieana provides important ecosystem services to the local societies of different regions living in the study area. In some areas, its collections lead to overexploitation and affect its populations. In the current study, we assess its populations across the province of Khyber Pakhtunkhwa. Our study records fewer seedlings in different regions which shows that it will be difficult for the species to cover the gap of all those individuals that die due to different biotic and abiotic factors. Various anthropogenic activities such as road construction (CPEC), forest fire, unplanned collections of leaves, palm heart collection, and expansion of forests to agricultural lands cause a big loss of the natural populations. Moreover, species uprooting by porcupines and bears as well as grazing of cattle and encroachment of *Prosopis juliflora* on *Nannorrhops ritchieana* habitats in different regions of Kohat, Hangu, Karak, Kurram, DIKhan are the severe threats to species conservation. In addition, plant age also has a crucial impact on the species fruiting ecology. Inflorescence size, fruit number, and fruit and seed size have their maximum in middle-aged palms, followed by young and then old plants. We conclude that it may be linked to their nutrient acquisition capacity. Plants at a young age might absorb nutrients in less amount than mature plants they are stout and strong while more than old plants because they are at the senescence stage. Therefore, young individuals have a lower output of fruit production than mature and higher than old plants. Implementation of The Kohat Mazri Control Act 1953 is obligatory throughout the region to conserve the species for future generations. On the other hand, further research is needed to completely understand the relationship of plant height with the fruiting ecology of the species.

CHAPTER 5

Who lives with whom and why? Ecological evaluation of *Nannorrhops ritchieana* (Griff.) Aitch. forests in the province of Khyber Pakhtunkhwa Pakistan

5.1 INTRODUCTION

Who lives with whom and why? It is an important question for researchers, biologists, environmentalists, biogeographers and all those who love and are curious about nature (McCune and Grace, 2002). Living organisms form intraspecific or interspecific associations and assemblages with each other (Abrams, 2001). A group of potentially linked species in the same habitat is termed a community (Leibold *et al*., 2004). It examines how linkages among species and their environment developed and how they in combination affect the diversity, distribution and abundance within an association or community (Johnson and Stinchcombe, 2007). Hundreds of studies in every biome of the globe have documented that plant species can have vital positive impacts on their associated plant species (Lortie *et al*., 2004). They facilitate each other in water absorption or by providing nutrients, organic matter, and many other essential substances (Brooker *et al*., 2008), and hence lead to diverse associations and communities. On the other hand, some plant species have been documented to have negative impacts on the surrounding neighboring species (Choler *et al*., 2001). They influence each other by shade effect, competition for nutrients acquisition and allelopathy (Qin *et al*., 2018). In this context answering the question of who lives with whom and why is crucial for understanding plant species distribution, associations, and community patterns and mechanisms.

Such questions could be answered by understanding the biotic and abiotic interactions of plants. Abiotic factors such as geography, climate, soil and topography have a substantial role in plant species distribution, growth and community formation (Lawler *et al*., 2015; Khan *et al*., 2017; Rehman *et al*., 2021). Plant communities' distribution pattern is due to climate, topography, soil, hydrology and many other gradients at various scales (Zhang *et al*., 2022), and hence they play a crucial role in the regulation and sustainability of the ecosystem (Nakamura, 2008).

Species with a charismatic role in the regulation of the ecosystem are termed keystone species (Chacón-Vargas *et al*., 2020). They are almost gregarious, and sociable and support other species in coexistence (Valladares *et al*., 2015). They provide habitat and shelter to other species from predators and herbivores and are hence called umbrella species (Heywood, 1995). The palm family (Arecaceae) is the leading family comprised of such gregarious and sociable organisms. Palms are the key functional elements of forest ecosystems (Balslev *et al*., 2011). They frequently occur in the form of dense clusters, cushions, or associations dominated by a single palm species such as *Sabal palmetto* in southeastern Mexico (Lopez and Dirzo, 2007), *Mauritia flexuosa* in the Amazon basin (Kahn and de Granville, 1992), *Lepidocaryum tenue* in the Amazon (Balslev *et al*., 2010), *Nannorrhops ritchieana* in the Hindukush Mountains (Abdullah *et al*., 2020). On the other hand, many palms co-exist with other plant species belonging to different genera in the form of complex associations (Balslev *et al*., 2011). Palm species' coexistence and the mechanisms involved in the assembly have been disentangled by some studies (Svenning 2001; Svenning *et al*., 2008; Bjorholm *et al*., 2008; Eiserhardt *et al*., 2011). According to several studies, species associations are also linked to environmental factors. Non-climatic factors such as soil, land use and topography are believed to be factors with a crucial role in controlling palm distribution, diversity and composition (Pearson and Dawson, 2003; Jones *et al*., 2006; Eiserhardt *et al*., 2011), and range determination at a large scale (Tuomisto 2007; Cámara-Leret *et al*., 2017). The distribution and abundance of many American palm species are linked with soil variables i.e., clay texture, aluminum content and other nutrients concentration (Svenning, 2001). Soil fertility at a local scale affects the distribution of *Borassus aethiopum* (Barot and Gignoux, 2003). In dry climates, soil types are linked to hydrology because the palms of dry regions are dependent on the groundwater table (Dransfield *et al*., 2008; Blach-Overgaard *et al*., 2010). Like other palms, *Nannorrhops ritchieana* prefers specific sorts of micro-environmental and edaphological conditions. It is of restricted distribution in the soil of special ultramafic rocks where Mg is found in maximum concentration, usually (Naseem *et al*., 2005) needs to be researched for climatic, topographic, edaphic and further different macro and micro-nutrients at a large scale. In this chapter, we focus on how various environmental variables affect *Nannorrhops ritcieana* and its associated flora distribution by using modern and advanced multivariate statistical techniques. We also identify different indicator species for each association.

5.2 MATERIALS AND METHODOLOGY

5.2. 1 Collection of ecological data

Before data collection, we reviewed various articles, reports, brochures and other documents to prepare a list of all regions of Khyber Pakhtunkhwa where *Nannorrhops ritchieana* is distributed. Then we planned visits for data collection. We used plots of different sizes following standard ecological quantitative approaches. Data were documented in a standard field book designed especially for *Nannorrhops ritchieana* ecological and functional traits data collection, including ecological attributes such as density, cover, and frequency. We then determined relative density, relative cover and relative frequency following Curtis and McIntosh (1950). We recorded geographical coordinates for each site using Garmin GPS. Mountain aspects were determined through Compass and general observations. We collected associated plant specimens from four zones namely eastern wet mountains (ii) northern dry mountains (iii) western dry mountains (iv) Sulaiman Piedmont. The collected specimens were pressed, properly dried, and poisoned with mercuric chloride. We identified about 80% of the associated species in the field while the remaining were identified with the help of different local floras and most importantly through the flora of Pakistan (http://www.efloras.org/flora_page.aspx?flora_id=5) and Wild flora of Swat Pakistan (Rehman, 2018). We further confirmed our plant names via a standard global plant list (https://wfoplantlist.org/plant-list) for further confirmation and authentication.

5.2.2 Soil gradients

We collected 500-gram soil samples for 508 plots from the rhizosphere of *Nannorrhops ritchieana* at a depth of 0-35cm. Pebbles and wood debris were removed from collected soil samples which were packed in zipper bags with proper tags of the respective plot number. At the end of each visit (usually one week) soil samples were shipped to the Ecology and Conservation Laboratory. Soil samples were shade dried at room temperature to avoid fungal colony formation. Dried samples were passed from sieves of different sizes for the determination of soil texture classes i.e., sand, silt and clay ratio.

5.2.3 Physicochemical Analysis

Soil physicochemical analyses were carried out in the plant ecology and conservation lab using different protocols. Soil pH was measured to determine soil acidity and basicity for all soil samples (Schirrmann *et al*., 2011) through sophisticated pH meter equipment. Soil electrical conductivity is widely used to determine different soil nutrients, and water contents by measuring free ions (cations and anions concentration). We used a modern electrical conductivity meter for all soil samples (Gali *et al*., 2012). Total dissolved solids were measured to calculate the organic and inorganic substances in the solid solutions using the total dissolved solids meter (Islam *et al*., 2016). We determined various micro and macronutrients in the soil through atomic absorption spectrometry techniques. One gram soil sample was taken and digested for 24 hours in a triacid mixture including HNO3, perchloric acid and H2SO4 in a 5:1:1 ratio, respectively. The digested mixture was placed on the hot plate for 10–15 minutes. After proper boiling and digestion, 20 ml of distilled water was added and then after the addition of distilled water soil samples were filtered using Whatman filter paper. The solution was filtered again to obtain transparency (Ali *et al*., 2018). The filtered samples were stored in a sterilized bottle for further analysis. The soil solutions were analyzed for different macro- and micronutrients using atomic absorption spectrometry techniques at the Department of Biochemistry, Quaid-i-Azam University Islamabad. We used blank solutions as a control (Akbar *et al*., 2021).

5.2.4 Climatic data collection

We gathered climate data from NASA for 63 populations comprising 508 plots. We used geographic coordinates of each population for the collection of climatic data and various variables such as specific humidity at 2-meter, relative humidity at two-meter, surface soil wetness, the temperature at two-meter maximum, the temperature at two-meter minimum, wind speed at two-meter maximum, wind speed at a two-meter minimum and precipitation. We collected forty years of data (1981–2021) for each population but in the current analysis, we use mean data to reduce the error chances.

5.2.5 Statistical analysis

Nannorrhops ritchieana and associated plants (251) importance value index (IVI) data, soil physicochemical data, soil texture and climate data files from 508 plots and 63 populations were arranged in MS Excel and CSV files according to the requirement of different statistical software i.e., PCORD, CANOCO, R-Programming, and Arc-GIS. Species area curves were constructed to know the adequacy of sampling for 251 plant species across 508 plots through PCORD (Zeb *et al*., 2021). A cluster dendrogram for each zone was constructed using PCORD software (Grandin, 2006). CANOCO software was used for Canonical Correspondence Analysis and Detrended Correspondence Analysis (Khan *et al*., 2019).

5.2.6 Indicator species analysis (ISA)

Indicator species analysis was carried out to determine three indicators (an herb, shrub and tree species) for each zone. It tells us about the fidelity of a species within that specific zone. Statistical significance was checked by doing Monte Carlo Test after the determination of indicator values following (Dufrene and Legendre, 1997). During the analysis, we calculated the relative abundance of the specific species of that zone to which the species belongs. Species with a threshold level of <25% Indicator value (IV) and < 0.05 % p* value were identified as indicator species.

5.2.7 Ecological attributes

5.2.7.1 Density and relative density (RD)

We determined species density in the field during data collection. Density is the total number of individuals of plants in a sampling plot. However, relative density is the percentage distribution of a species in a plot. It was determined following (Oosting, 1956) as;

$$\text{Density} = \frac{\text{Number of individuals of a plant in a plot}}{\text{The total area of the plot}}$$

$$\text{Relative density } = \frac{\text{Number of individuals of a plant}}{\text{Total number of individuals of all plants sampled}} \text{ x100}$$

5.2.7.2 Frequency and relative frequency (R.F)

Frequency is the degree of percentage distribution of a species across the total plots in which the species occurs. Moreover, relative frequency is the degree of the percentage distribution of a species in relation to the frequencies of all species sampled in a region. It was determined following Hussain (1989).

$$\text{Frequency} = \frac{\text{Number of plots in which a species is present}}{\text{Total number of plots studied}} \text{ x100}$$

$$\text{Relative frequency} = \frac{\text{Frequency of a species}}{\text{Total frequencies of all species}} \text{x100}$$

5.2.7.3 Diameter at breast height, cover and relative cover

It is the basal area covered by a tree, shrub and herb species. It was assessed through direct observations and measurements in the field. The formula for cover is.

$$\text{Cover} = \frac{\text{Total basal area of all individuals of a species}}{\text{The total size of the plot}}$$

The basal area occupied by a species in relation to the total area occupied by other associated species. It is calculated as,

$$\text{Relative cover} = \frac{\text{Cover of all individuals of a species}}{\text{Total cover of all species}} \text{x100}$$

Herbs and Shrubs cover was then estimated by using (Braun-Blanquet, 1932) cover classes. Various Braun-Blanquet, canopy cover classes are given in Table 5.2.1.

Table 5.2.1 Braun-Blanquet canopy cover classes

Cover Class	percentage Cover Range	percentage Cover Midpoint
1	< 0.1	0.05
2	0.1-1	0.55
3	1-5	3
4	5-25	15
5	25-50	37.5
6	50-75	62.5
7	75-95	85
8	95-99	97
9	>99	99.5

For trees, the circumference at breast height (CBH) was measured with a measuring tape in inches. The measured values were converted to centimeters and then meters to evaluate the basal area.

$$CBH(cm) = CBH\ (inch) \times 2.54 \ldots\ldots\ldots \text{Eq (i)}$$

$$\text{CBH(m)} = \frac{\text{Circumference at breast height (cm)}}{100} \ldots\ldots\ldots\ldots \text{Eq (ii)}$$

To find the radius of CBH, the value of ‘r’ was obtained by using the formula of circumference i.e.,

$$C = 2\pi r \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq(iii)}$$

$$\text{r} = \frac{\text{Circumference at breast height (m)}}{2\pi} \ldots\ldots \text{Eq (iv)}$$

The value of π is 3.1416 constant.

5.2.7.4 Importance value index (IVI)

The importance value index was calculated following (Curtis and McIntosh, 1950; Khan, 2012). The sum of relative density, relative frequency, and relative cover was divided by three.

$$\text{IVI} = \frac{RD + RF + RC}{3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq (v)}$$

5.3 RESULTS

5.3.1 Species Area Curves (SAC)

Species-area curves are mostly used in the field of vegetation ecology to understand the adequacy or pattern of species richness with sampling plots. We measured the SAC through PCORD for 252 plant species recorded in 508 plots (including *Nannorrhops ritchieana*). The average distance curve incorporated the statistics on the species abundance and IVI to comprehend a subsample size that provides a constant species composition. The SAC analysis showed that the curve for species climbs to the point of stability and becomes parallel after plot 498, as no additional plant species were recorded after that point. The species curve line reached the asymptote which justified the adequacy of sampling plots in the studied regions (Figure, 5.3.1).

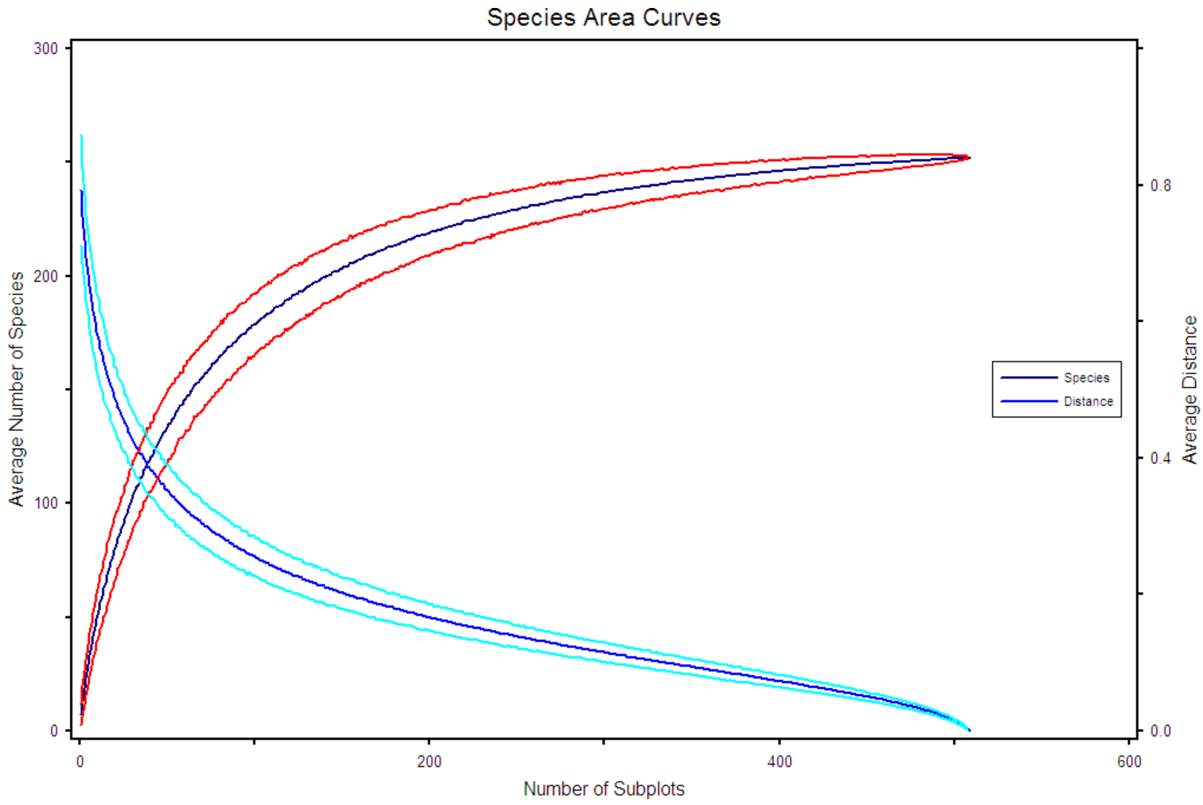


Figure 5.3.1 Species area curves diagram showing sampling adequacy

5.3.2 Floristic composition

Floristically our study regions are rich and have a great abundance and diversity of plants. In current research work, we were selective while selecting plots. We just sampled all those plots where *Nannorrhops ritchieana* occurred. We recorded a total of 251 plant species (belonging to 68 different families) from 508 plots across 63 stations. Habit wise we recorded 177 herb species (70%), 40 shrub species (16%), and 37 tree species (14%) which showed that the major contribution was by herbs as compared to shrubs and trees (Figure, 5.3.2). The dominant families were Poaceae represented by 31species, followed by Fabaceae (25 species), Asteraceae (24 species), Lamiaceae (20 species), Boraginaceae (12 species), and Amaranthaceae (12 species). The remaining families all had less than 10 species each (Figure, 5.3.3, Table 5.3.2).

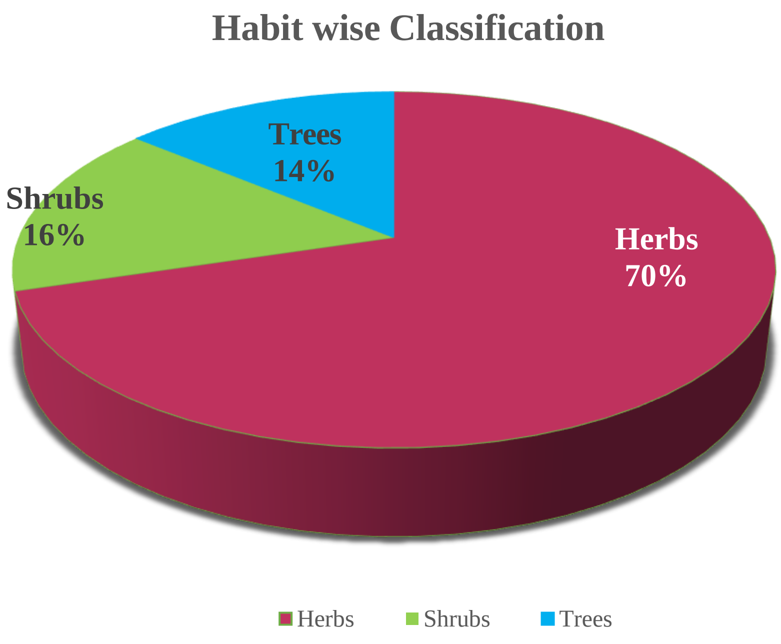


Figure 5.3.2 Habit-wise classification of all plant species collected in association with *Nannorrhops ritchieana*

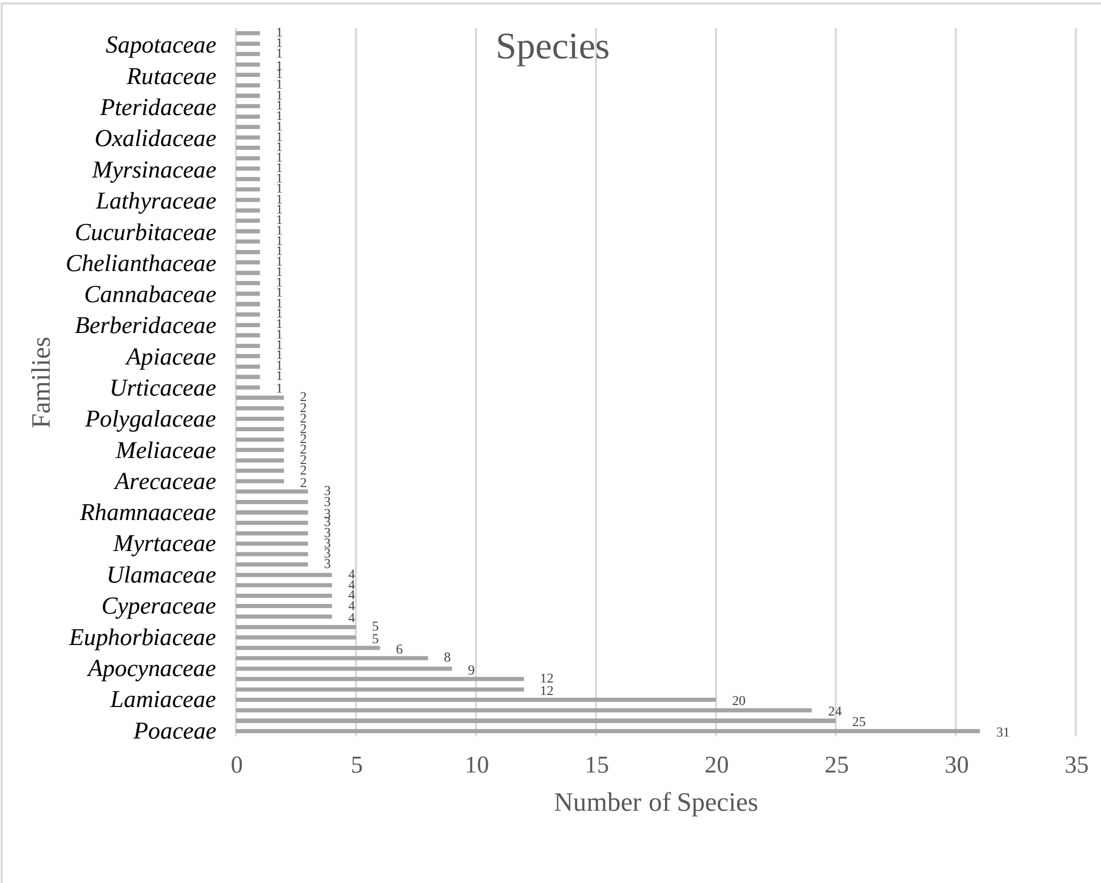


Figure 5.3.3 Family-wise classification of all plant species collected in association with *Nannorrhops ritchieana*

Table 5.3.2 Plant species with their family name, habit, individual records and IVI

S. No	Habit	Plant name	Family	IR	IVI
1	Herb	*Abutilon indicum* (L.) Sweet	Malvaceae	10	256.6095
2	Herb	*Achyranthes aspera* L.	Amaranthaceae	4	42.71504
3	Herb	*Acrachne racemosa* (B.Heyne ex Roth) Ohwi	Poaceae	6	87.7437
4	Herb	*Adiantum caudatum* L.	Pteridaceae	28	588.8497
5	Herb	*Aerva javanica* Juss.	Amaranthaceae	42	770.5138
6	Herb	*Ajuga integrifolia* Buch.-Ham.	Lamiaceae	25	278.0817
7	Herb	*Ajuga parviflora* Benth.	Lamiaceae	12	332.8888
8	Herb	*Alhagi maurorum* Medik.	Fabaceae	8	195.3533
9	Herb	*Allium griffithiamum* Boiss.	Lilliaceae	10	188.6491
10	Herb	*Alternanthera pungens* Kunth	Amaranthaceae	4	58.91733
11	Herb	*Amaranthus retroflexus* L.	Amaranthaceae	6	87.97287
12	Herb	*Amaranthus viridis* All.	Amaranthaceae	53	1013.414
13	Herb	*Aristida setacea* Retz.	Poaceae	25	402.9621
14	Herb	*Androsace rotundifolia* Hardw.	Primulaceae	57	1117.521
15	Herb	*Asparagus racemosus* Willd.	Asparagaceae	13	151.2295
16	Herb	*Argyrolobium roseum* Jaub. & Spach	Fabaceae	17	261.3427
17	Herb	*Anagallis arvensis* L.	Primulaceae	6	140.9576
18	Herb	*Artemisia scoparia* Maxim.	Asteraceae	2	61.38888
19	Herb	*Argemone mexicana* L.	Papaveraceae	6	117.5571
20	Herb	*Asplenium ceterach* L.	Apleniaceae	4	88.53955
21	Herb	*Phagnalon niveum* Edgew.	Asteraceae	9	159.7792
22	Herb	*Launaea procumbens* (Roxb.) Amin	Plumbaginaceae	20	367.5217
23	Herb	*Bromus japonicus* Houtt.	Poaceae	5	62.65871
24	Herb	*Cajanus platycarpus* (Benth.) Maesen	Fabaceae	17	326.2634
25	Herb	*Boerhavia diffusa* L.	Nectaginaceae	38	683.1296

26	Herb	*Boerhavia procumbens* Banks ex Roxb.	Nectaginaceae	8	165.519
27	Herb	*Brachiaria ramosa* Stapf	Poaceae	6	103.1408
28	Herb	*Astragalus psilocentros* Fisch.	Fabaceae	3	49.05553
29	Herb	*Calendula arvensis* L.	Asteraceae	3	47.96485
30	Herb	*Carthamus oxyacanthus* M.Bieb.	Asteraceae	16	243.8967
31	Herb	*Cenchrus ciliaris* L.	Poaceae	37	611.9814
32	Herb	*Cymbopogon jwarancusa* (Jones ex Roxb.) Schult.	Poaceae	6	96.69682
33	Herb	*Cheilanthes acrostica* (Balb.) Tod.	Chelianthaceae	7	95.7393
34	Herb	*Chenopodium botrys* L.	Amaranthaceae	32	577.0436
35	Herb	*Chenopodium album* Bosc ex Moq.	Amaranthaceae	7	145.0895
36	Herb	*Chenopodium murale* L.	Amaranthaceae	12	215.6865
37	Herb	*Chrozophora tinctoria* (L.) A.Juss.	Boraginaceae	11	143.0992
38	Herb	*Chrysopogon aucheri* Stapf	Poaceae	39	565.9938
39	Herb	*Cirsium arvense* (L.) Scop.	Asteraceae	6	96.41452
40	Herb	*Cucurbita colocyntha* Link	Cucurbitaceae	5	90.36353
41	Herb	*Cleome brachycarpa* Vahl ex DC.	Cleomaceae	3	54.9737
42	Herb	*Commelina benghalensis* L.	Commelinaceae	8	199.1889
43	Herb	*Convolvulus arvensis* L.	Convolvulaceae	8	201.1454
44	Herb	*Erigeron canadensis* L.	Asteraceae	2	38.69279
45	Herb	*Corchurus tridens* L.	Malvaceae	8	143.6826
46	Herb	*Cousinia thomsonii C.B.Clarke*	Fabaceae	21	372.6755
47	Herb	*Crotalaria medicaginea Lam.*	Fabaceae	42	805.8909
48	Herb	*Cymbopogon commutatus (Steud.) Stapf*	Poaceae	71	1699.726

49	Herb	*Cymbopogon distans (Nees ex Steud.) W.Watson*	Poaceae	4	71.83442
50	Herb	*Cymbopogon martini (Roxb.) W.Watson*	Poaceae	22	491.4505
51	Herb	*Centaurea iberica Trevir. ex Spreng.*	Asteraceae	84	2101.184
52	Herb	*Cynodon dactylon (L.) Pers.*	Poaceae	18	341.6356
53	Herb	*Cynoglossum lanceolatum* Forssk.	Boraginaceae	37	822.281
54	Herb	*Cyperus niveus* Retz.	Cyperaceae	45	945.5182
55	Herb	*Cyperus rotundus* L.	Cyperaceae	69	1908.373
56	Herb	*Desmostachya bipinnata* (L.) Stapf	Poaceae	102	2399.78
57	Herb	*Dichanthium annulatum* Stapf	Poaceae	50	878.1826
58	Herb	*Dicliptera bupleuroides* Nees	Acanthaceae	15	316.3311
59	Herb	*Echinochloa colona* (L.) Link	Poaceae	13	256.8981
60	Herb	*Echinops echinatus* Roxb.	Asteraceae	7	124.9873
61	Herb	*Equisetum arvense* L.	Equisetaceae	85	1413.958
62	Herb	*Erigeron bonariensis* L.	Asteraceae	24	443.3845
63	Herb	*Eragrostis cilianensis* (All.) Vignolo ex Janch.	Poaceae	1	9.34405
64	Herb	*Eriophorum angustifolium* Honck.	Cyperaceae	9	167.9218
65	Herb	*Erodium cicutarium* (L.) L'Hér.	Primulaceae	5	62.24577
66	Herb	*Euphorbia hirta* L.	Euphorbiaceae	106	2816.264
67	Herb	*Euphorbia hispida* Boiss.	Euphorbiaceae	22	464.8248
68	Herb	*Euphorbia prostrata* Aiton	Euphorbiaceae	9	169.1192
69	Herb	*Crotalaria linifolia* L.f.	Fabaceae	9	177.0301
70	Herb	*Zygophyllum indicum* (Burm.f.) Christenh. & Byng	Zygophyllaceae	19	366.8875
71	Herb	*Filago hurdwarica* (Wall. ex DC.) Wagenitz	Asteraceae	8	110.5443

72	Herb	*Forsskaolea tenacissima* L.	Urticaceae	12	201.3487
73	Herb	*Heliotropium europaeum* Forssk.	Boraginaceae	3	23.59964
74	Herb	*Euploca strigosa* (Willd.) Diane & Hilger	Boraginaceae	12	288.7391
75	Herb	*Heliotropium muelleri* (I.M.Johnst.) Craven	Boraginaceae	4	89.92592
76	Herb	*Indigofera linifolia* (L.f.) Retz.	Fabaceae	7	163.2981
77	Herb	*Ipomoea purpurea* (L.) Roth	Convolvulaceae	3	48.31302
78	Herb	*Origanum majorana* L.	Lamiaceae	1	20.72222
79	Herb	*Malcolmia africana* (L.) W.T.Aiton	Brassicaceae	3	43.88889
80	Herb	*Lepidium sativum* L.	Brassicaceae	13	212.8829
81	Herb	*Lespedeza juncea* (L.f.) Pers.	Fabaceae	48	778.1429
82	Herb	*Limonium cabulicum* Kuntze	Plumbaginaceae	14	180.9298
83	Herb	*Malvastrum coromandelianum* (L.) Garcke	Malvaceae	17	370.0631
84	Herb	*Marrubium vulgare* L.	Lamiaceae	7	118.2572
85	Herb	*Medicago polymorpha* L.	Fabaceae	30	412.9081
86	Herb	*Micromeria biflora* Benth.	Lamiaceae	79	1201.8
87	Herb	*Nanorrhinum ramosissimum* (Wall.) Betsche	Plantaginaceae	4	107.1607
88	Herb	*Nepeta erecta* Benth.	Lamiaceae	6	126.2546
89	Herb	*Oenothera rosea* Aiton	Onagraceae	3	60.78655
90	Herb	*Onosma hispida* Wall. & G.Don	Boraginaceae	9	148.6378
91	Herb	*Origanum vulgare* L.	Lamiaceae	14	220.3365
92	Herb	*Oxalis corniculata* L.	Oxalidaceae	83	1504.151
93	Herb	*Parthenium hysterophorus* Adans.	Asteraceae	2	48.3583
94	Herb	*Paspalum distichum* L.	Poaceae	14	354.1312
95	Herb	*Peganum harmala* L.	Zygophyllaceae	16	374.8692
96	Herb	*Vicoa vestita* Benth. & Hook.f.	Asteraceae	6	144.8519

97	Herb	*Pentanema spiraeifolium* (L.)	Asteraceae	15	258.8098
98	Herb	*Phlomoides spectabilis (Falc. ex Benth.) Kamelin & Makhm.*	Lamiaceae	22	432.3527
99	Herb	*Physalis peruviana* L.	Solanaceae	4	78.4959
100	Herb	*Plantago major* L.	Plantaginaceae	2	34.14141
101	Herb	*Isodon rugosus* (Wall.) Codd	Lamiaceae	3	42.46866
102	Herb	*Polygala abyssinica* R.Br. ex Fresen.	Polygalaceae	8	156.2324
103	Herb	*Polygala arvensis* Willd.	Polygalaceae	6	72.37508
104	Herb	*Polygonum aviculare* L.	Polygonaceae	4	69.94057
105	Herb	*Polygonum paronychioides* C.A.Mey.	Polygonaceae	12	201.4343
106	Herb	*Polygonum plebeium* R.Br.	Polygonaceae	4	82.44424
107	Herb	*Portulaca oleracea* L.	Portulacaceae	4	71.13888
108	Herb	*Portulaca quadrifida* L.	Portulacaceae	6	195.4047
109	Herb	*Decalepidanthus parviflorus* (Decne.) Dickoré & Hilger	Boraginaceae	6	77.02517
110	Herb	*Rhazya stricta* Decne.	Apocynaceae	6	125.1655
111	Herb	*Rhynchosia minima* (L.) DC.	Fabaceae	9	172.9106
112	Herb	*Rumex hastatus* D.Don	Polygonaceae	22	323.7553
113	Herb	*Saccharum bengalense* Retz.	Poaceae	9	157.5115
114	Herb	*Saccharum munja* Roxb.	Poaceae	1	11.22004
115	Herb	*Saccharum spontaneum* L.	Poaceae	28	583.5043
116	Herb	*Phlomoides superba* (Royle ex Benth.) Kamelin & Makhm.	Lamiaceae	4	59.27401
117	Herb	*Salvia moorcroftiana* Wall. ex Benth.	Lamiaceae	15	253.5676
118	Herb	*Salvia reflexa* Hornem.	Lamiaceae	32	887.3119
119	Herb	*Scutellaria linearis* Benth.	Fabaceae	1	23.16667
120	Herb	*Scutellaria scandens* Buch.-Ham. ex D.Don	Fabaceae	2	31

121	Herb	*Setaria pumila* Roem. & Schult.	Poaceae	11	272.8376
122	Herb	*Arenaria serpyllifolia* L.	Caryophyllaceae	8	115.9107
123	Herb	*Carex fedia* Nees ex Wight	Cyperaceae	2	48.7037
124	Herb	*Sisymbrium irio* L.	Brassicaceae	4	125.1095
125	Herb	*Solanum incanum* Kit. ex Schult.	Solanaceae	5	49.03003
126	Herb	*Solanum nigrum* L.	Solanaceae	3	55.83333
127	Herb	*Solanum virginianum* L.	Solanaceae	20	299.097
128	Herb	*Solanum villosum* Mill.	Solanaceae	3	91.42835
129	Herb	*Launaea nudicaulis* Less.	Asteraceae	3	46.09185
130	Herb	*Launaea secunda* Hook.f.	Asteraceae	3	42.77778
131	Herb	*Sonchus oleraceus* L.	Asteraceae	11	171.1567
132	Herb	*Sorghum halepense* Pers.	Poaceae	9	226.5459
133	Herb	*Spergularia diandra* (Guss.) Heldr.	Nyctaginaceae	5	44.92158
134	Herb	*Stachys biflora* Hook. & Arn.	Lamiaceae	3	122.8381
135	Herb	*Stellaria media* (L.) Vill.	Caryophyllaceae	2	13.66953
136	Herb	*Suaeda vermiculata* Forssk. ex J.F.Gmel.	Amaranthaceae	12	281.4319
137	Herb	*Symphyotrichum grandiflorum* (L.) G.L.Nesom	Asteraceae	18	296.3021
138	Herb	*Rumex dentatus* L.	Polygonaceae	9	151.3955
139	Herb	*Digera muricata* Mart.	Amaranthaceae	1	27.66667
140	Herb	*Convolvulus prostratus* Forssk.	Convolvulaceae	2	31.66239
141	Herb	*Lepidium didymum* L.	Brassicaceae	2	50.87408
142	Herb	*Datura innoxia* Mill.	Solanaceae	1	37.80803
143	Herb	*Torilis leptophylla* Rchb.f.	Apiaceae	4	73.93858
144	Herb	*Galium aparine* L.	Rubiaceae	4	51.03968
145	Herb	*Poa annua* L.	Poaceae	1	41.11111
146	Herb	*Phragmites karka* (Retz.) Trin. ex Steud.	Poaceae	3	58.35165

147	Herb	*Polygonum virgatum* Cham. & Schltdl	Polygonaceae	1	25.40402
148	Herb	*Eleusine indica* Gaertn.	Poaceae	4	56.71351
149	Herb	*Panicum antidotale* Retz.	Poaceae	3	114.8779
150	Herb	*Asphodelus tenuifolius* Cav.	Asphoedelaceae	2	16.8386
151	Herb	*Avena fatua* L.	Poaceae	2	45.13227
152	shrub	*Phalaris minor* Retz.	Poaceae	1	20.44444
153	Herb	*Vincetoxicum petrense* (Hemsl. & Lace) Rech.f.	Apocynaceae	1	32.82051
154	Herb	*Sida cordata* (Burm.f.) Borss.Waalk.	Malvaceae	1	32.88889
155	Herb	*Nonea pulchella* Pacz.	Boraginaceae	3	63.25926
156	Herb	*Tagetes erecta* L.	Asteraceae	2	14.0303
157	Herb	*Tagetes minima* L.	Asteraceae	12	128.0098
158	Herb	*Taraxacum officinale* F.H.Wigg.	Asteraceae	7	114.1601
159	Shrub	*Rubus ellipticus Sm*	Rosaceae	11	88.231
160	Herb	*Teucrium stocksianum* Boiss.	Lamiaceae	23	321.889
161	Herb	*Themeda anathera* Hack.	Poaceae	3	142.4712
162	Herb	*Thymus linearis* Benth.	Lamiaceae	11	231.9125
163	Herb	*Tinospora hirsuta* (Becc.) Forman	Apocynaceae	2	13.79487
164	Herb	*Tithonia* spp	Asteraceae	6	170.1109
165	Herb	*Tragopogon gracilis* D.Don	Poaceae	50	932.3826
166	Herb	*Tribulus terrestris* L.	Zygophyllaceae	19	413.8723
167	Herb	*Trichodesma indicum* R.Br.	Boraginaceae	7	176.0931
168	Herb	*Medicago monantha* (C.A.Mey.) Trautv.	Fabaceae	2	31.88889
169	Herb	*Tulipa clusiana* Redouté	Asteraceae	1	21.73504
170	Herb	*Verbascum thapsus* L.	Scrophuliaraceae	21	331.9852
171	Herb	*Verbena hybrida* Groenl. & Rumpler	Verbenaceae	2	37.55556
172	Herb	*Verbena officinalis* L.	Verbenaceae	8	91.02662

173	Herb	*Vicia sativa* L.	Fabaceae	5	81.66442
174	Herb	*Viola canescens* Wall.	Violaceae	1	16.30952
175	Herb	*Viola odorata* L.	Violaceae	2	24.9117
176	Herb	*Rostraria cristata* (L.) Tzvelev	Poaceae	28	681.9962
177	Herb	*Withania coagulans* (Stocks) Dunal	Solanaceae	22	434.4243
178	Herb	*Withania somnifera* (L.) Dunal	Soalanaceae	3	41.08232
179	Shrub	*Xanthium spinosum* L.	Asteraceae	3	85.88889
180	Shrub	*Arundo donax* L.	Poaceae	2	42.73504
181	Shrub	*Barleria cristata* Lam.	Acanthaceae	14	452.3073
182	Shrub	*Berberis lycium* Royle	Berberidaceae	2	21.03968
183	Shrub	*Buddleja crispa* Benth.	Scrophulariaceae	5	150.734
184	Shrub	*Buxus papillosa* C.K.Schneid.	Buxaceae	2	42.73504
185	Shrub	*Calotropis procera* (Aiton) Dryand.	Apocynaceae	3	57.2726
186	Shrub	*Cannabis sativa* L.	Cannabaceae	6	123.2099
187	Herb	*Carissa spinarum* L.	Apocynaceae	2	32.24868
188	Shrub	*Clematis grata* Wall.	Ranunculaceae	1	21.42857
189	Shrub	*Colebrookea oppositifolia* Sm.	Lamiaceae	3	71.7903
190	Shrub	*Cotoneaster nummularius* Fisch. & C.A.Mey.	Rosaceae	9	155.5617
191	Shrub	*Daphne mucronata* Royle	Thymelaeaceae	27	584.3516
192	Shrub	*Dodonaea viscosa* Jacq.	Sapinaceae	81	2888.989
193	Shrub	*Grewia asiatica* L.	Malvaceae	23	457.917
194	Shrub	*Gymnosporia royleana* M.A.Lawson	Celastraceae	92	2421.846
195	Shrub	*Hiptage benghalensis* (L.) Kurz	Malpighiaceae	1	19.41458
196	Shrub	*Indigofera heterantha* Wall. ex Brandis	Fabaceae	8	229.3946
197	Shrub	*Justicia adhatoda* L.	Acanthaceae	9	173.0132
198	Shrub	*Lantana camara* L.	Verbenaceae	5	101.3994

199	Shrub	*Lippia alba* (Mill.) N.E.Br. ex Britton & P.Wilson	Verbenaceae	5	89.53465
200	Shrub	*Myrsine africana* L.	Myrsinaceae	2	50.41269
201	Shrub	*Nannorrhops ritchieana* (Griff.) Aitch.	Arecaceae	508	39179.14
202	Shrub	*Nerium oleander* L.	Apocynaceae	4	104.3284
203	Shrub	*Periploca aphylla* Decne.	Apocynaceae	23	589.3583
204	Shrub	*Periploca calophylla* (Wight) Falc.	Apocynaceae	9	273.8609
205	Shrub	*Periploca hydaspidis* Falc.	Apocynaceae	39	968.3901
206	Shrub	*Plecteranthus rugosus* (Wall.) Codd	Lamiaceae	6	116.2888
207	Shrub	*Rosa moschata* Herrm.	Rosaceae	5	129.5521
208	Shrub	*Rubus fruticosus* Marshall	Rosaceae	9	182.5977
209	Shrub	*Rydingia integrifolia* (Benth.) Scheen & V.A.Albert	Lamiaceae	4	72.30718
210	Shrub	*Rydingia limbata* (Benth.) Scheen & V.A.Albert	Lamiaceae	22	390.144
211	Shrub	*Rydingia persica* (Burm.f.) Scheen & V.A.Albert	Lamiaceae	4	108.3265
212	Shrub	*Sageretia thea* (Osbeck) M.C.Johnst.	Rosaceae	15	237.4688
213	Shrub	*Sarcococca saligna* Müll.Arg.	Buxaceae	3	66.58944
214	Shrub	*Senna occidentalis* (L.) Link	Fabaceae	2	47.09048
215	Shrub	*Sophora mollis* (Royle) Graham ex Baker	Fabaceae	4	101.038
216	Shrub	*Xanthium strumarium* Lour.	Asteraceae	9	128.1075
217	Tree	*Acacia modesta* Wall.	Fabaceae	9	550.4873
218	Tree	*Acacia nilotica* (L.) Willd. ex Delile	Fabaceae	20	1539.053
219	Tree	*Bauhinia variegata* L.	Fabaceae	1	100
220	Tree	*Broussonetia papyrifera* (L.) Vent.	Moraceae	3	133.3853

221	Tree	*Capparis decidua* Edgew.	Capparaceae	20	1529.598
222	Tree	*Celtis australis* L.	Cannabaceae	5	190.692
223	Tree	*Celtis caucasica* Willd.	Cannabaceae	13	885.0771
224	Tree	*Cotinus coggygria* Scop.	Anacardiaceae	3	144.6495
225	Tree	*Dalbergia sissoo* Roxb. ex DC.	Fabaceae	2	188.3401
226	Tree	*Eucalyptus camaldulensis* Dehnh.	Myrtaceae	3	259.3328
227	Tree	*Eucalyptus globulus* Labill.	Myrtaceae	1	21.31746
228	Tree	*Ficus carica* L.	Moraceae	11	645.1403
229	Tree	*Grewia tenax* (Forssk.) Fiori	Ulmaceae	3	169.2933
230	Tree	*Mallotus philippensis* (Lam.) Müll.Arg.	Euphorbiaceae	4	221.4228
231	Tree	*Melaleuca citrina* (Curtis) Dum.Cours.	Myrtaceae	1	34.44444
232	Tree	*Melia azedarach* L.	Meliaceae	7	396.7836
233	Tree	*Morus alba* L.	Moraceae	20	1218.354
234	Tree	*Morus nigra* L.	Moraceae	15	1091.984
235	Tree	*Olea ferruginea* Wall. ex Aitch.	Oleaceae	47	3254.023
236	Tree	*Phoenix dactylifera* L.	Arecaceae	34	2139.426
237	Tree	*Pinus roxburghii* Sarg.	Pinaceae	13	725.6695
238	Tree	*Prosopis juliflora* (Sw.) DC.	Fabaceae	40	3085.546
239	Tree	*Punica granatum* L.	Lathyraceae	14	882.9581
240	Tree	*Pyrus pseudopashia* T.T.Yu	Rosaceae	4	87.59339
241	Tree	*Quercus baloot* Griff.	Fagaceae	2	140.117
242	Tree	*Salvadora oleoides* Decne.	Salvadoraceae	11	598.4174
243	Tree	*Sapium sebiferum* (L.) Roxb.	Euphorbiaceae	5	245.2151
244	Tree	*Sideroxylon mascatense* (A.DC.) T.D.Penn.	Sapotaceae	9	488.9687
245	Tree	*Taverniera cuneifolia* (Roth) Ali	Fabaceae	1	8.203704
246	Tree	*Tecomella undulata* Seem.	Bignoniaceae	1	36.50794

247	Tree	*Toona ciliata* M.Roem.	Toona ciliata M.Roem.	1	19.86551
248	Tree	*Vachellia nilotica* (L.) P.J.H.Hurter & Mabb.	Fabaceae	6	433.8107
249	Tree	*Zanthoxylum armatum* DC.	Rutaceae	4	99.5524
250	Tree	*Ziziphus jujuba* Mill.	Rhamnaceae	8	677.7778
251	Tree	*Ziziphus nummularia* (Burm.f.) Wight & Arn.	Rhamnaceae	6	369.1297
252	Tree	*Ziziphus oxyphylla* Edgew.	Rhamnaaceae	7	168.7414

5.3.3 Classification of the study area into different zones

We classified the study region into different zones using generalized linear model (GLM) and canonical correspondence analysis (CCA) techniques. All the sampling plots were classified into four zones under the influence of environmental gradients using the generalized linear model (Ahmad *et al*., 2020; Khan *et al*., 2021) techniques. We further confirmed it through CCA with environmental gradients. All sampling plots (508) were grouped into four zones i.e., (i) eastern wet mountains (ii) northern dry mountains (iii) western dry mountains (iv) Sulaiman Piedmont (Figure, 5.3.4, Figure, 5.3.5).

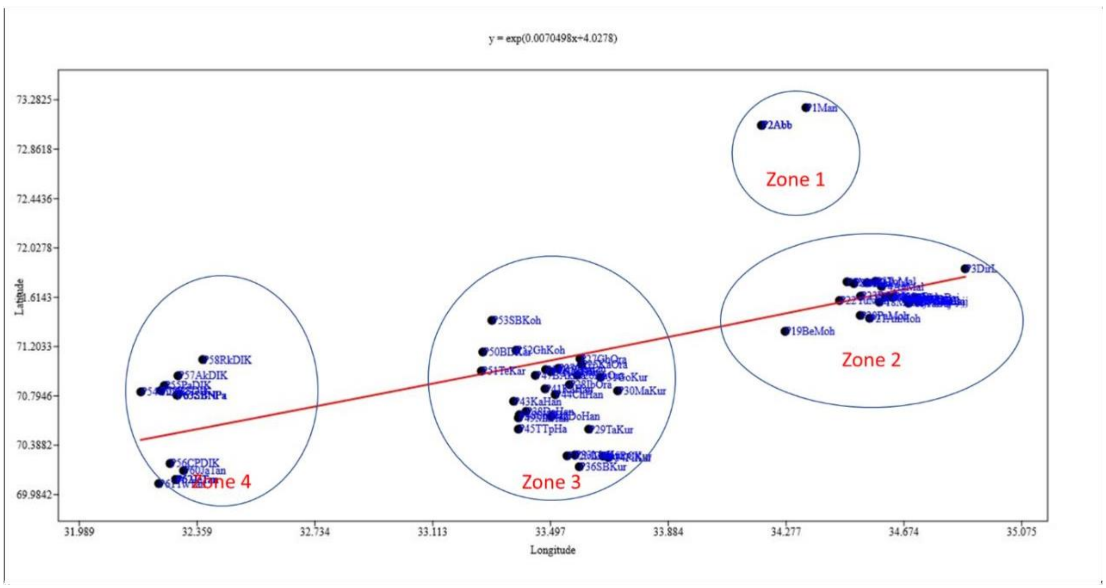


Figure 5.3.4 Generalized linear model of different transects or populations

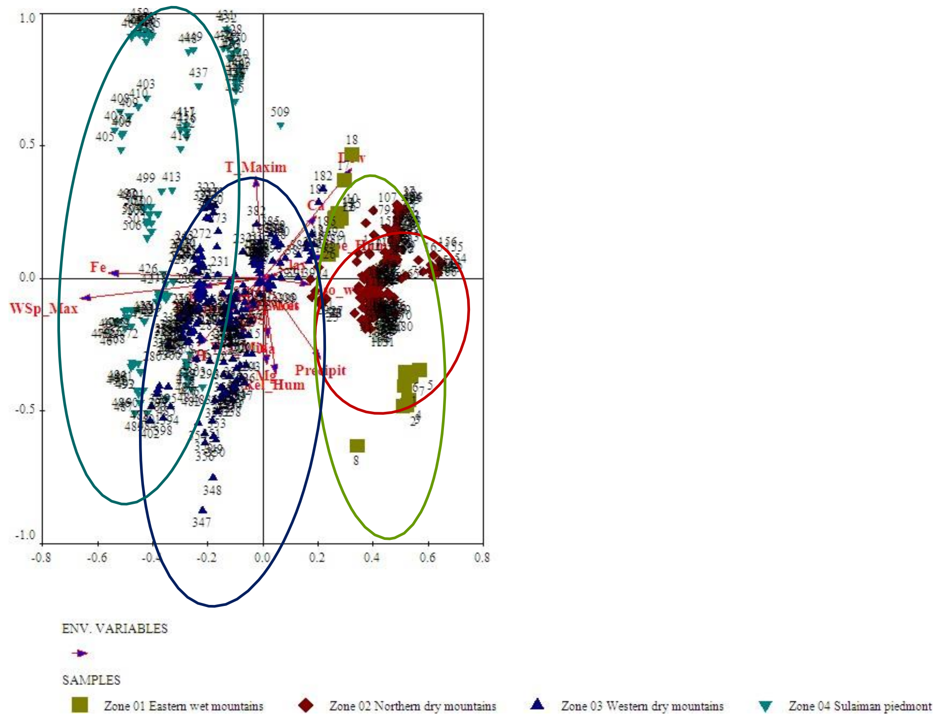


Figure 5.3.5 Classification of plots into different zones in relation to the environment using canonical correspondence analysis (CCA)

5.3.4 Association 01 Eastern Wet Mountains Zone

This association is comprised of 16 sampling plots located in the Himalayan range (Figure. 5.3.6), different from other associations of the study area in terms of associated plant species, topography and climate (Appendix 5.1). In this zone, we explored two populations of *Nanorrhops ritchieana*, (Figure 5.3.6) a population in Mansehra (34.34N; 73.21E) and one in Abbottabad (34.19°N; 73.06°E). In Manshera the *Nanorrhops ritchieana* population grows along the main bye-pass on the western slope of the mountain while the 2nd population is located at the Sherwan village on the western slope of the mountain within the *Pinus roxburghii* forests. *Pyrus psuedopashia*, *Daphane mucronate*, and *Androsace rotundifolia* are the indicator species of this zone (Table 5.3.3, Figure 5.3.7). *Zanthoxylum armatum*, *Olea ferruginea*, *Pinus roxburghi* are the dominant tree species, *Lantana camara*, *Colebrookea oppositifolia*, and *Dodonaea viscosa* are the dominant shrubs, and *Lepidium didymus*, *Amaranthus viridis*, and *Oxalis corniculata* are the dominant herb species of this zone.

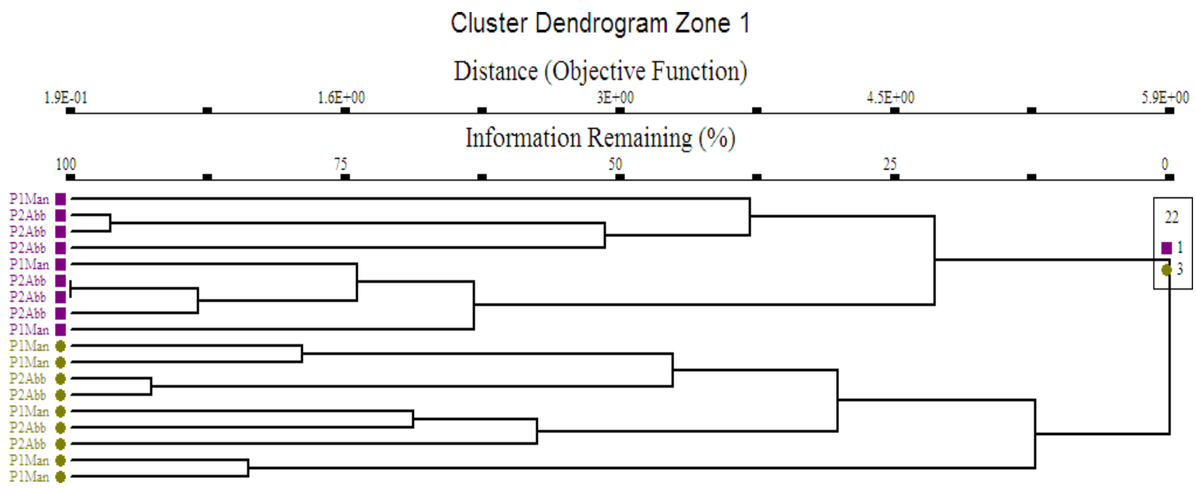


Figure 5.3.6 Cluster analysis of association 01 eastern wet mountains zone

Table 5.3.3 Summary table of indicator species of the 01 Association

EnvGradients	**Indicator species**	**Maxgrp**	**IV**	**Mean**	**S.Dev**	**p*value**	**Zone**	**IVI**
Precipitation	*Pyrus pseudopashia*	42	91.3	13.6	14.58	0.0032	1	87.59
Wind speed maximum	*Pyrus pseudopashia*	61	91.3	13.8	12.93	0.0024	1	87.59
Humidity	*Pyrus pseudopashia*	73	97.4	9	11	0.0016	1	87.59
Wind speed minimum	*Daphne mucronata*	6	100	12.1	12.27	0.001	1	99.55
Altitude	*Androsace rotundifolia*	34	39	16.4	5.59	0.0062	1	82.98
Sodium	*Androsace rotundifolia*	5	18.2	5.3	2.79	0.03	1	82.98

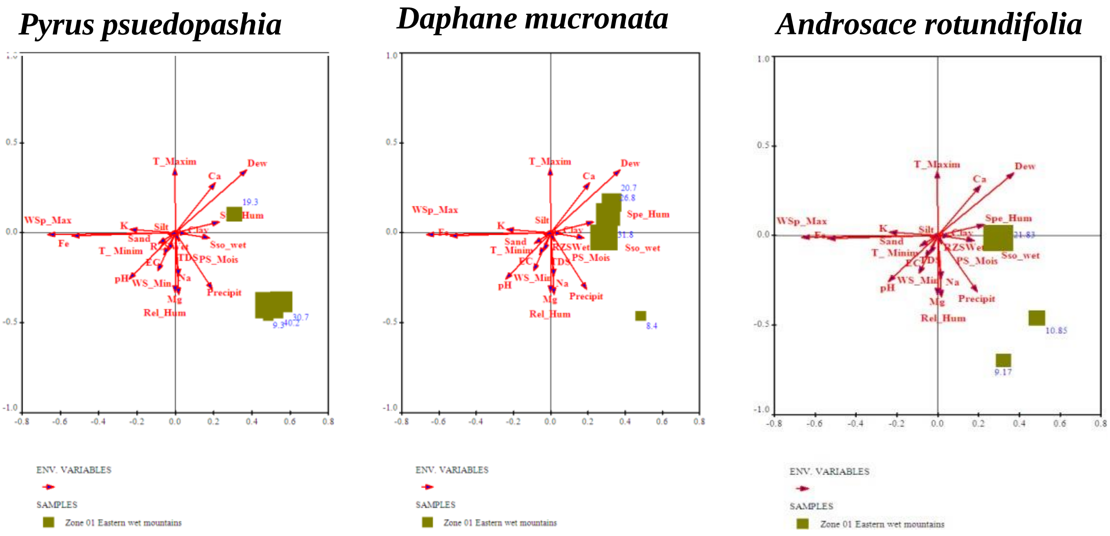


Figure 5.3.7 Data attribute plots of the three indicator plants of Association 01

5.3.5 Association 02 Northern Dry Mountains Zone

This association is comprised of 164 plots located in the Hindukush range of mountains different from other associations of the study area in terms of plant species, topography, geochemistry, and climate (Appendix 5.2). The hierarchical cluster dendrogram of this zone is further categorized into four sub-clusters (Figure 5.3.8). All four sub-clusters are formed from plots from different regions clumped in a mixed array, i.e., plots from the populations of Dir are clumped with that of Bajaur, Malakand and Mohmand rather than clumping with other plots of the population of Dir (Figure 5.3.8). In this zone, we explored 21 populations in different areas of Dir, Bajaur, Malakand and Mohmand. It starts from district Dir in the east (34.88E; 71.85N) to Mohamnd in the West Bergina village along the river Kabul (34.27E; 71.31N). In Dir Lower, the population is established in the Islam Dara village Maidan Valley. It is in an isolated population disturbed by anthropogenic activities. In Bajaur and Malakand it is distributed in some valleys on the western slope while in some regions on the eastern slopes, with dense cushions. Moreover, in Mohmnad district it has a sporadic type of distribution with old and large size individuals. In Yusaf Baba it forms cushions like those of Malaknad and Bajaur along the gorges of river Panjkora. *Melia azedarch*, *Rydingia limbata*, *Verbascum thapsus* are the indicators of different environmental gradients of this association (Figure 5.3.9, Table 5.3.2). *Mallotus philippensis*, *Ailanthus altissima*, *Ficus carica*, *Olea ferruginea*, *Sideroxylon mascatense* are the dominant tree species. *Dodonaea viscosa*, *Indigofera heterantha* and *Gymnosporia* *royleana* are the dominant shrubs while *Dicanthium annulatum, Cenchrus ciliaris, Centurea iberica,* and *Micromeria biflora* are the dominant herb species of this association.

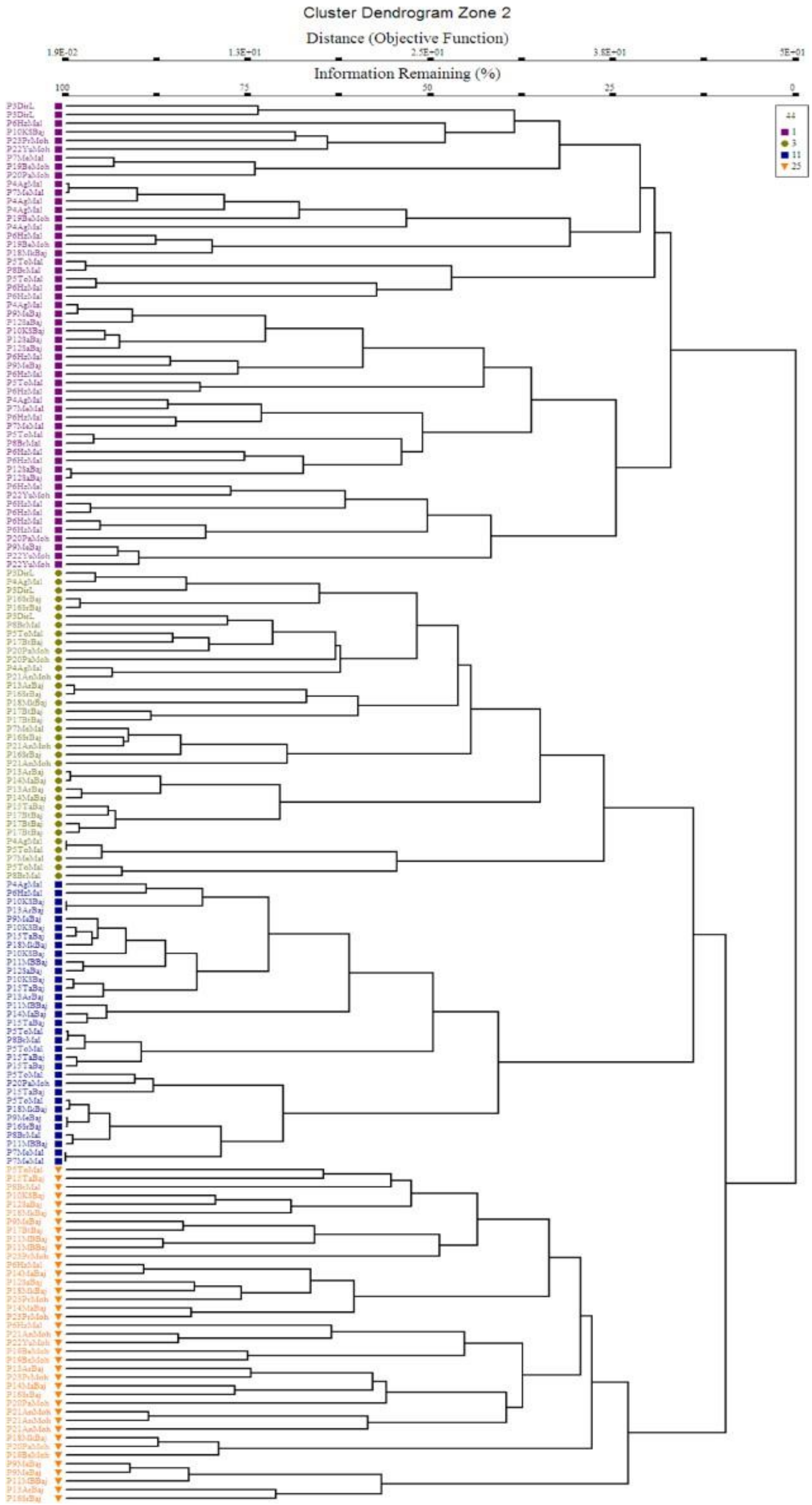


Figure. 5.3.8 Cluster analysis of association 02 northern dry mountains zone

Table 5.3.2 Summary table of indicator species of the 02 Association

Env. Gradients	Indicator species	Maxgrp	IV	Mean	S.Dev	p*	Zone
Longitude	*Rydingia limbata*	73	45.6	9.4	11.95	0.0164	2
Precipitation	*Rydingia limbata*	21	47.3	14.9	15.56	0.0494	2
Altitude	*Verbascum thapsu*	34	25.7	13.9	5.45	0.0474	2
Calcium	*Melia azedarch*	5	60.7	15.2	10.47	0.0102	2
Potassium	*Melia azedarch*	4	70.7	21.9	13.47	0.0152	2
Profile Soil Wetness	*Melia azedarch*	57	92	19.8	13.54	0.0042	2
Root Zone Soil Wetness	*Melia azedarch*	34	92	19.8	13.39	0.0044	2
Humidity	*Melia azedarch*	72	75.5	20.9	13.39	0.013	2
Surface Soil Wetness	*Melia azedarch*	51	58.7	18.3	10.17	0.0188	2
Wind Speed maximum	*Melia azedarch*	13	67.4	18.4	12.2	0.0168	2

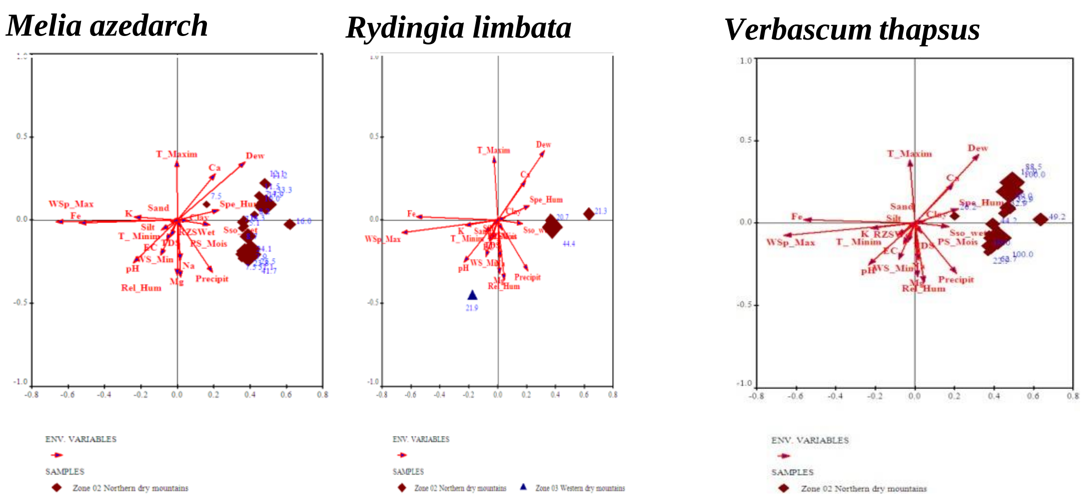


Figure 5.3.9 Data attribute plots of the topmost three indicator plants of association 02

5.3.6 Association 03 Western Dry Mountains zone

This association is comprised of 221 plots located in the Hindukush range of mountains (Figure 5.3.10). It covers different regions of Khyber, Orakzai, Kurram, Hangu, Kohat and Karak. It is distinguished from other associations of the study area in terms of associated plant species, topography, geochemistry, and climate (Appendix 5.3). In this zone, we explored 29 populations. This zone starts from the Pakistan-Afghanistan border at Torkham in Khyber (34.10E;71.12N) and ends at the Pakistan-Afghanistan border, Haider Zaman Fort Lower Kurram (33.59E; 70.20N). The hierarchical cluster dendrogram of this zone is further divided into five sub-clusters (Figure 5.3.10). In the first subcluster cold areas of the central Kurram, i.e., Tindu, Marghan and Govaki are clustered with upper regions of Orakzai and Hangu. Moreover, the remaining four clusters are combinations of plots from different populations means they are mixed types of associations (Figure 5.3.10). In the Torkham region of Khyber *Nannorrhops ritchieana* has sporadic distribution with small leaves and narrow leaf segments. The associated plants are *Fagonia indica*, *Peganum harmala*, *Aristida adscensionis* and a few others. On the other hand, the Kurram Valley, Orakzai, and Hangu host *Nannorrhops ritchieana* with great abundance. Especially Kurram Valley has characteristic forests of *Nannorrhops ritchieana* in Marghan, Govaki, and along the border with Afghanistan near Haider Zaman Fort associated with different plant species. Moreover, in Karak and Kohat the species form some important associations with *Acacia nilotica*, *Acacia modesta* and various other species. *Capparis decidua*, *Periploca aphylla* and *Convolulus prostratus* are the indicators of different environmental gradients of this association (Table 5.5, Figure 5.3.11).

Acacia modesta, Punica granatum, Acacia nilotica and *Prosopis juliflora* are the dominant tree species of this zone. *Gymnosporia royleana, Dodonaea viscosa*, *Withania coagulans* and *Ziziphus spina-christi* are the dominant shrub species while *Fagonia indica*, *Peganum harmala*, *Salvia reflexa*, and *Parthenium hysterophorus* are the dominant herb species. *Parthenium hysterophorus* is a noxious weed encroaching from the plains of Kohat, Karak and Hangu to the uplands of Hangu, Kurram, and Orakzai and affecting the indigenous plant diversity.

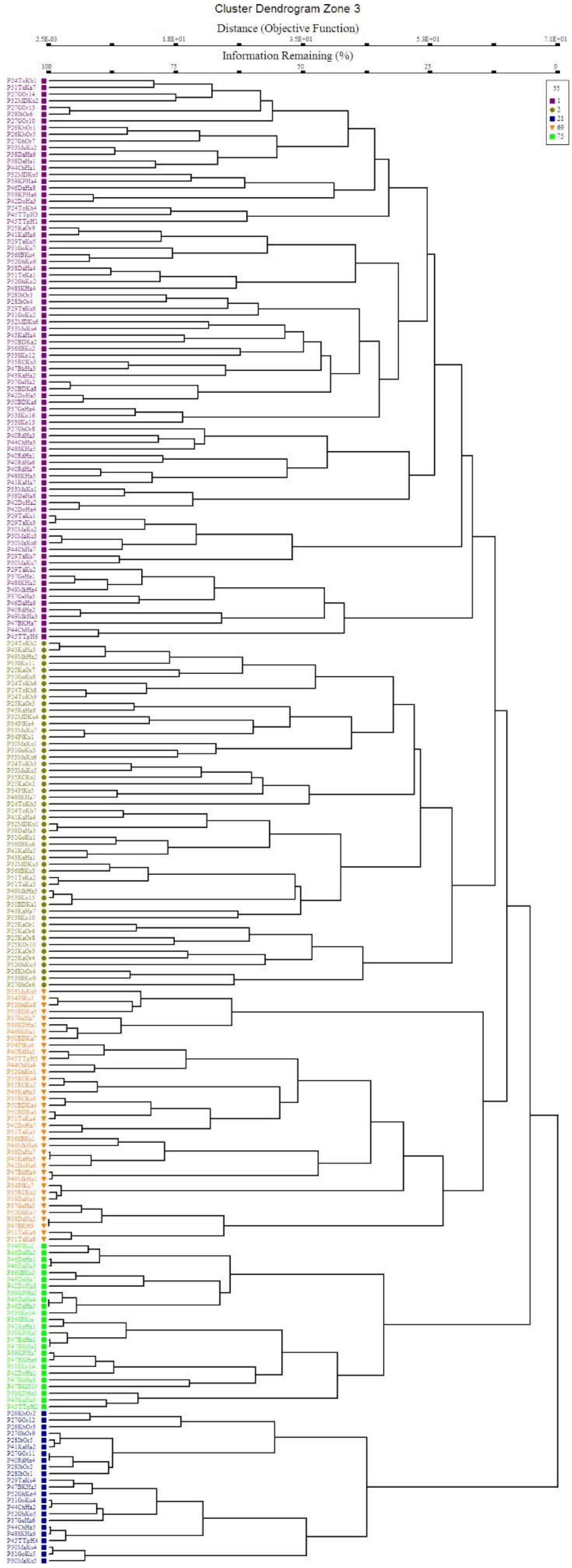


Figure 5.3.10 Cluster analysis of association 03 western dry mountains zone

Table 5.3.5 Summary of indicator species of the association 03

Env. Gradients	Indicator species	Maxgrp	IV (Value)	Mean	S.Dev	p*	Zone
Magnesium	*Periploca aphylla*	4	53	19.8	9.27	0.0064	3
pH	*Periploca aphylla*	6	49.3	18.9	10.09	0.031	3
Altitude	*Periploca aphylla*	32	37.6	15.3	5.8	0.0078	3
Tem-Min	*Periploca aphylla*	1	57.3	17.1	8.93	0.0036	3
Dew	*Periploca aphylla*	2	62	19.8	11.06	0.0088	3
Dew	*Capparis decidua*	1	58.8	18.1	10.29	0.0094	3
Precipitation	*Capparis decidua*	4	45.6	21.9	15.21	0.0228	3
Silt	*Capparis decidua*	80	94.9	29	12.08	0.0058	3
Tem-Min	*Capparis decidua*	1	65.9	14.7	8.74	0.0012	3
Altitude	*Capparis decidua*	32	59.4	10	4.85	0.0002	3
Longitude	*Convolvulus prostratus*	73	49.5	7.1	9.98	0.0176	3
Precipitation	*Convolvulus prostratus*	2	49.7	10.4	13.76	0.0528	3
Wind Speed maximum	*Convolvulus prostratus*	6	48.4	12.1	12.17	0.056	3

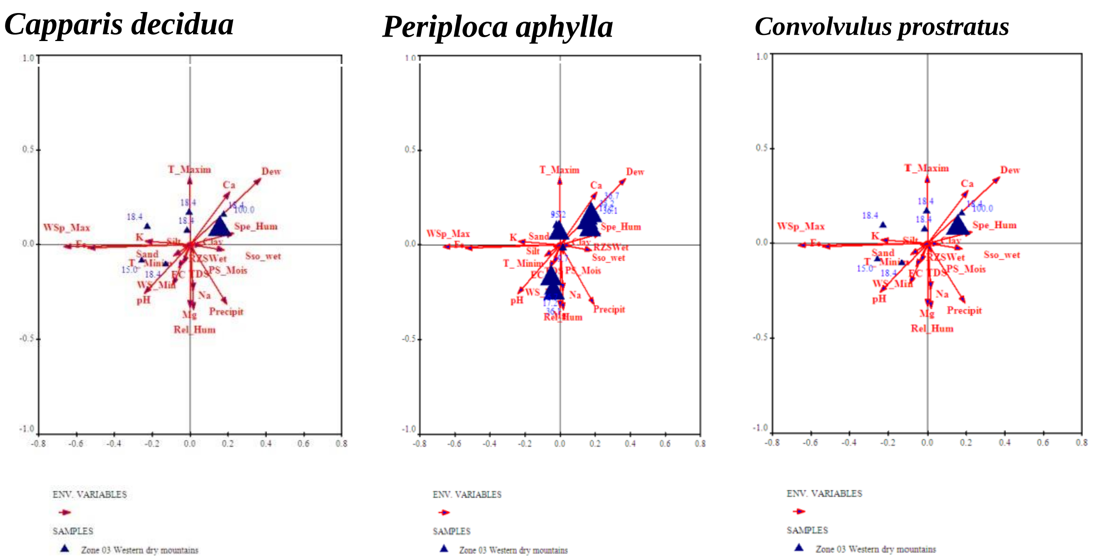


Figure 5.3.11 Data attribute plots of three indicator species of association 03

5.3.7 Association 04 Sulaiman Piedmont Zone

This association covers various areas of D I Khan, Lakimarwat, and Tank, comprised of 107 plots across 11 populations (Figure, 5.3.12). As the name indicates it is in the hilly terrains and plains in the foothills of the Sulaiman range of mountains. It has a unique climate, topography and geochemistry (Appendix 5.4). This zone is drier than the other three zones. In DIKhan along the China-Pakistan Economic Corridor (CPEC), *Nannorrhops ritchieana* has large individuals with silvery-colored leaves. Moreover, in the hilly region of Sheikhbadin National Park, it has small individuals than DIKhan occurs in association with *Dodonaea viscosa*, *Indigofera hetarantha*, *Nerium oleander*, *Grevia tenax*, *Abutilon indicum*, *Asparagus racemosus,* and *Taverniera cuneifolia* (Roth) Ali, etc. This zone covers the area from Rehmani Khel DIKhan (32.42E; 70.98N) to Tank Jadola (32.31E; 70.17N). The cluster dendrogram of this zone shows four subzones (Figure, 5.3.11). The 1st zone formation is found between the Gilloti region of DIKhan with Tank Jandola. On the other hand, the population sampled along the Waziristan border in Tank clumped in a separate cluster. It is drier than the other region growing on poor rocks in association with *Periploca callophylla*, *Echinops echinatus Taverniera cuneifolia* and a few species of grass. The third and fourth clusters are combinations of plots from DIKhan, Tank and Sheikhbadin National Park with diverse associated plant species. *Phoenix dactylifera*, *Rhazya stricta,* and *Aerva javanica* are the indicator species of this association on different environmental gradients (Table 5.3.6, Figure 5.3.12).

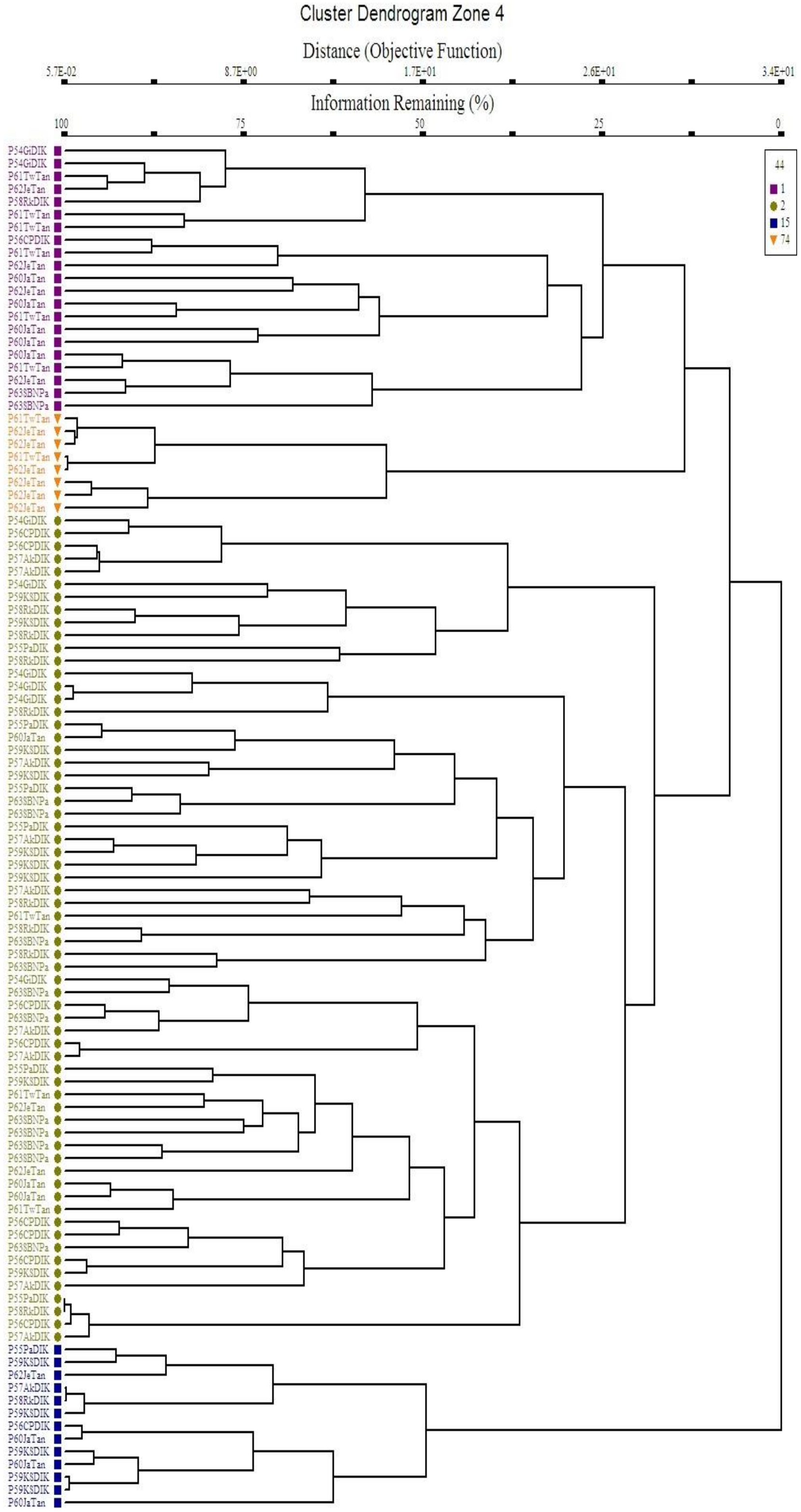


Figure 5.3.12 Cluster Analysis of association 04 Sulaiman Piedmont zone

Table 5.3.6 Summary table of indicator species of the 04 Association

Env Gradients	**Indicator species**	**Maxgrp**	**IV**	**Mean**	**S.Dev**	**p***	**Zone**
Sand	*Aerva javanica*	10	40	23	11.27	0	4
T Min	*Aerva javanica*	2	8	14	8.22	1	4
Alti	*Aerva javanica*	32	27	7.6	4.26	0	4
Mg	*Aerva javanica*	13	71	22.8	10.87	0	4
Mg	*Rhazya stricta*	18	69	22.9	11.26	0	4
Tem	*Rhazya stricta*	44	25	14.3	8.74	0	4
WS2Max	*Phoenix dactylifera*	17	53	18.3	7.77	0	4
Altitude	*Phoenix dactylifera*	32	51	19.5	5.91	0	4
Silt	*Phoenix dactylifera*	12	30	18.6	6.16	0	4
Dew	*Phoenix dactylifera*	7	43	21	10.15	0	4
Tmax	*Phoenix dactylifera*	81	53	18.3	7.77	0	4

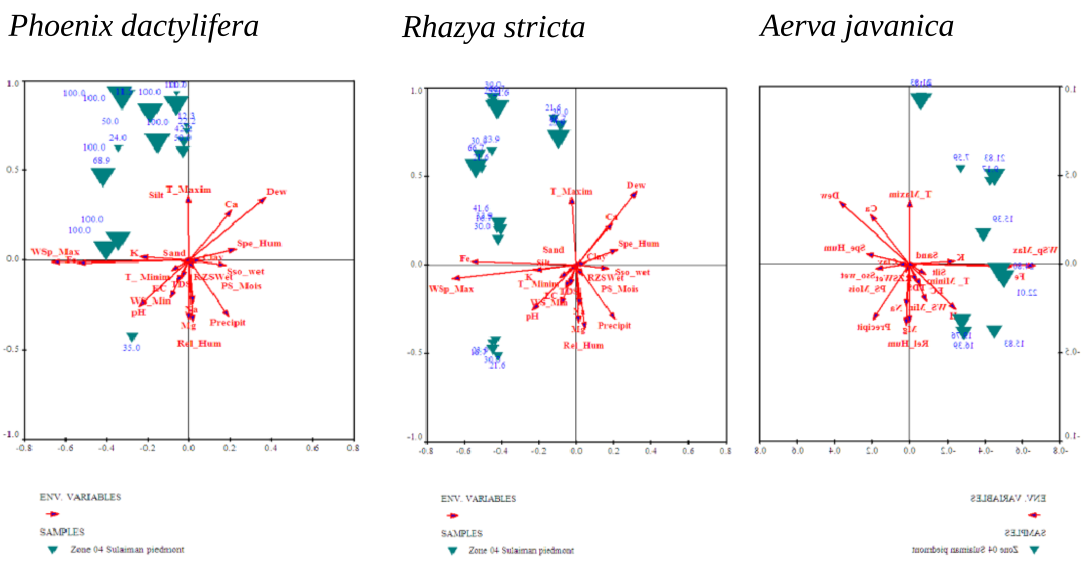


Figure. 5.3.13 Data attribute plots of the topmost three indicator species of association 04 western dry mountains zone

5.3.8 Various environmental factors and their range in Nannorrhops ritchieana habitat

We assessed different environmental factors through different techniques and then linked them with *Nannorrhops ritchieana* population across different zones of the study area. We found that the species has an indispensable relationship with magnesium and calcium. It is mostly distributed in different regions with different soil chemistry mostly comprised of soap stones, marble stones and different others. The soapstone is mainly comprised of magnesium, calcium and iron. On the other hand, the marble stone is mostly composed of calcium carbonates and magnesium compounds. In the western dry mountains zone in Kohat and Karak region, the species is distributed in saline rocks where the sodium is in higher concentration. In the eastern wet mountains, the highest concentration of electrical conductivity and total dissolved solids were recorded. Similarly, in Kurram Valley in the western dry mountain zone, both aforementioned factors were high. In the Sulaiman Piedmont zone, the maximum temperatures were recorded and the soil was a silty loamy type. The palm in this region forms an oasis sort of vegetation.

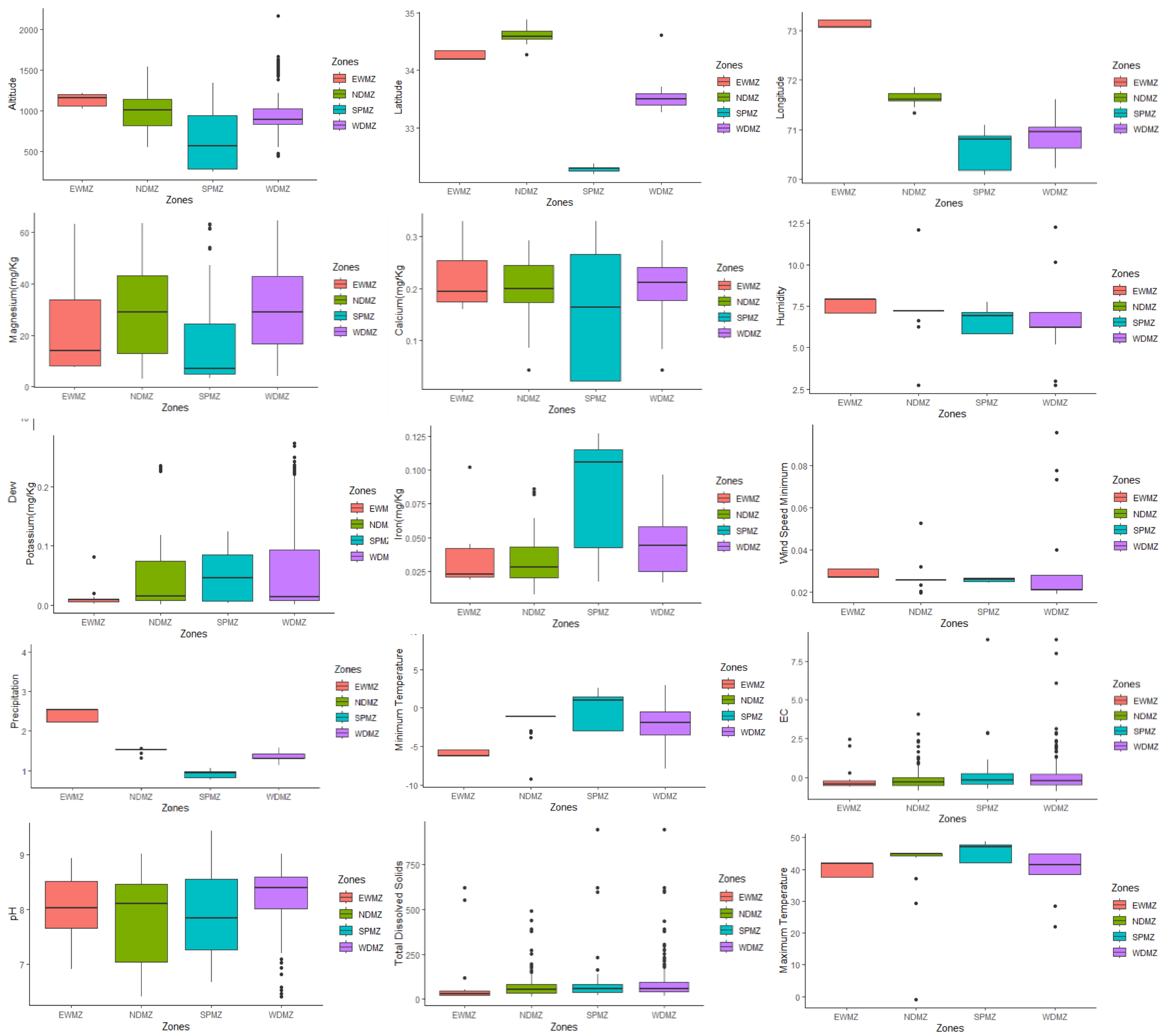


Figure 5.3.14 Boxplots showing the variations of the studied environmental variables of the four plant associations

5.3.9 Canonical correspondence analysis (CCA) of plant species

We use the direct ecological gradient canonical correspondence analysis (CCA) techniques to know the distribution of different plant species concerning environmental gradients. The CCA analysis of plant species distributed all plants in a complex array throughout the studied regions. It demonstrated that the environmental gradients, i.e., minimum and maximum temperature, precipitation, wind speed, humidity, surface soil wetness, EC, pH, TDS, magnesium, calcium, iron, sodium, and potassium play a crucial role in the distribution and determination of various plant species. The sum of all eigenvalues is 29.998 and the sum of all canonical eigenvalues is 2.103 (Table, 5.3.7). Each quadrant or axes in the CCA ordination biplot shows groups of plant species clumped in relation to various environmental gradients. Plant species influenced by similar factors or with a direct positive relationship were categorized in one quadrant while dissimilar ones were grouped in different quadrants. On the other hand, the length and direction of arrows ordered the correlation among the environmental gradients in the biplot while the green color triangles denoted plant species (251). In the 1st quadrant, we found mostly species that are controlled by humidity, dew, clay, and calcium. On the 1st axes or quadrant, the eigenvalue is 0.296, the value of the species-environment correlation is 0.859, and the cumulative percentage variance of species data is 1.0 while the cumulative percentage of species-environment relation is 14.1. Interestingly among these species, *Argyrolobium roseum*, *Clematis grata*, *Amaranthus viridis*, *Adiantum capillus-veneris*, *Pentanema vestitum*, *Teucrium stocksianum*, *Carissa spinarum*, *Buddleja crispa*, *Rubus fruiticosus* are controlled by the maximum rate of humidity and dew. They occur mostly on the north faces of mountains and landscapes where the humidity and dew are abundant. On the other hand, *Capparis decidua*, *Acacia modesta*, *Cenchrus ciliaris*, *Agremone mexicana*, *Ziziphus spina-christi* and many others are controlled by the lower level of humidity, precipitation, and dew (Table 5.3.7). On the 2nd quadrant of the CCA *Solanum virginianum*, *Rhazya stricta*, *Phoenix dactylifera*, *Aerva javanica*, *Phagnalon niveum*, *Suaeda vermiculata*, *Senna occidentalis*, *Euploca strigosa*, *Nanorrhinum ramosissimum*, *Cyperus niveus*, *Dichanthium annulatum*, *Alternanthera pungens*, *Solanum incanum* and many others are distributed in relation to high temperature and iron contents (Figure 5.3.14). The eigenvalue for this axis is 0.296, the value of the species-environment correlation is 0.779 and the cumulative percentage variance of species data is 1.7. The cumulative percentage of species-environment relation is 24.0 (Table, 5.3.7).

The third axis forms a clump of different environmental variables such as pH, EC, TDS, Sand, Wind speed maximum and Minimum temperature. The eigenvalue for this axis is 0.176, the value of the species-environment correlation is 0.724 and the cumulative percentage variance of species data is 2.3. The cumulative percentage of species-environment relation is 32.3. Species of different zones are distributed on this quadrant in relation to various environmental gradients, i.e., *Adathoda vesica*, *Sageratia thea*, *Symphyotrichum grandiflorum*, *Medicago monantha*, *Olea ferruginea*, *Malvastrum coromandelianum*, *Rhynchosia minima*, *Punica granatum*, *Gymnosporea royleana* and many others. On the 4th quadrant, the plant species are mostly controlled by climatic factors such as relative humidity, precipitation, and surface soil wetness. The eigenvalue for this quadrant is 0.154, the value of the species-environment correlation is 0.764 and the cumulative percentage variance of species data is 2.8. The cumulative percentage of species-environment relation is 39.7 (Table, 5.3.7). This quadrant of the CCA biplot grouped *Zanthoxylum armatum*, *Brossunatia papyrifera*, *Sapium sebiferum*, *Cannabis sativa*, *Sophora mollis*, *Lantan camara*, *Morus alba*, *Quercus baloot*, *Ficus carica*, *Sarcococca saligna*, *Xanthium strumarium*, *Asplenium cetarch*, *Rumex dentatus*, *Parthenium hysterophorus*, *Cynodont dactylon* and many others. The deep observation of this zone reflects that the invasive species *Parthenium hysterophorus, Cannabis sativa*, *Lantan camara*, *Xanthium strumarium*, *Brossunatia papyrifera* and *Cynodon dactylon* the noxious weeds grass is grouped in this quadrant under the influence of relative humidity, precipitation, and surface soil wetness. It proves that the invasion of these species is strongly linked to climate. We observed that the invasive species easily encroach in nutrient-rich habitats, and they form interspecific associations. The most common is the association of *Lantana camara Brossunatia papyrifera*. *Parthenium hysterophorus*, *Cannabis sativa* and *Xanthium strumarium* association. It will be of high interest to study whether their relationships are supportive or dangerous for each other. A few questions arise from the associations of invasive species. (i) Do they compete and play a tug of war for nutrient acquisition? (ii) Do they support in terms of habitat provision to each other?

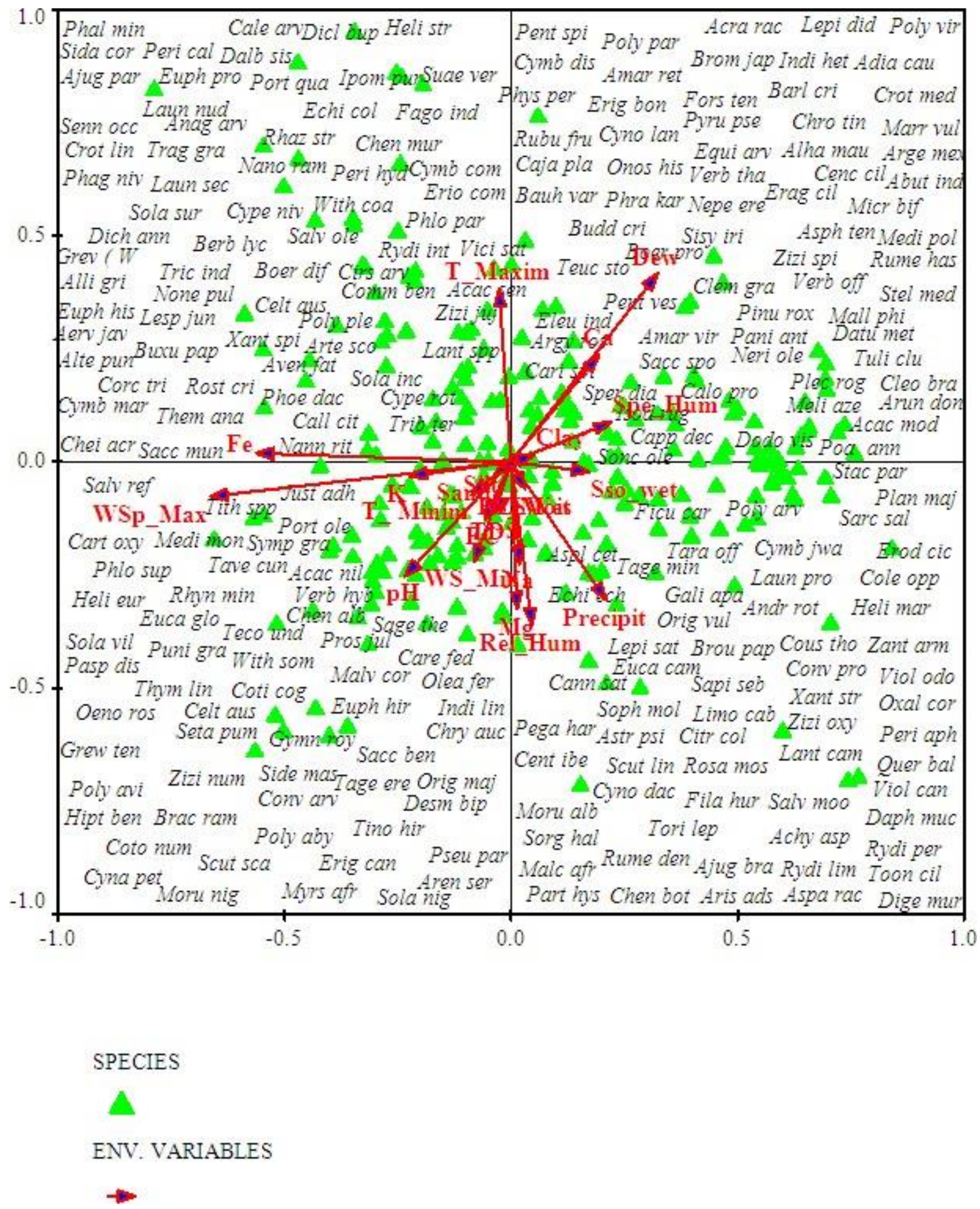


Figure 5.3.15 Canonical correspondence analysis (CCA) of plant species under the influence of different environmental variables

Table 5.3.7 Canonical correspondence analysis (CCA) of plant species with different environmental variables

Axes	**1**	**2**	**3**	**4**	**Total inertia**
Eigenvalues	0.296	0.209	0.176	0.154	29.998
Species-environment correlations	0.859	0.779	0.724	0.764	
Cumulative percentage of the variance of species data	1	1.7	2.3	2.8	
Cumulative percentage of species-environment relation	14.1	24	32.3	39.7	
The sum of all eigenvalues					29.998
A sum of all canonical eigenvalues					2.103

5.3.10 Floristic homologies across different zones

Our venn diagram illustrates the homology and differences in species composition among different zones. It is an important, effective, and easy way of graphical illustration to compare different groups. EWM zone has eight unique species which are only confined to this zone. It shares four species with the NDM zone, five with the WDM zone, and five with the SPM Zone. On the other hand, the NDM zone has 20 unique species and it shares 31 species with the WDM zone and seven species with the SPM Zone. The WDM zone has 27 unique species and shares 25 species with the SPM zone. Sixteen species are common among the EWM zone, NDM zone and WDM zone. Sixteen species are common among EWM zone, NDM zone and WDM zone. Five species are common among the EWM zone, WDM zone and SPM zone. Three species are common among the EWM zone, NDM zone and SPM zone. Fifty-four species are common among the NDM zone, WDM zone and SPM zone. Moreover, 34 species are commonly occurring in all zones (Figure 5.3.15).

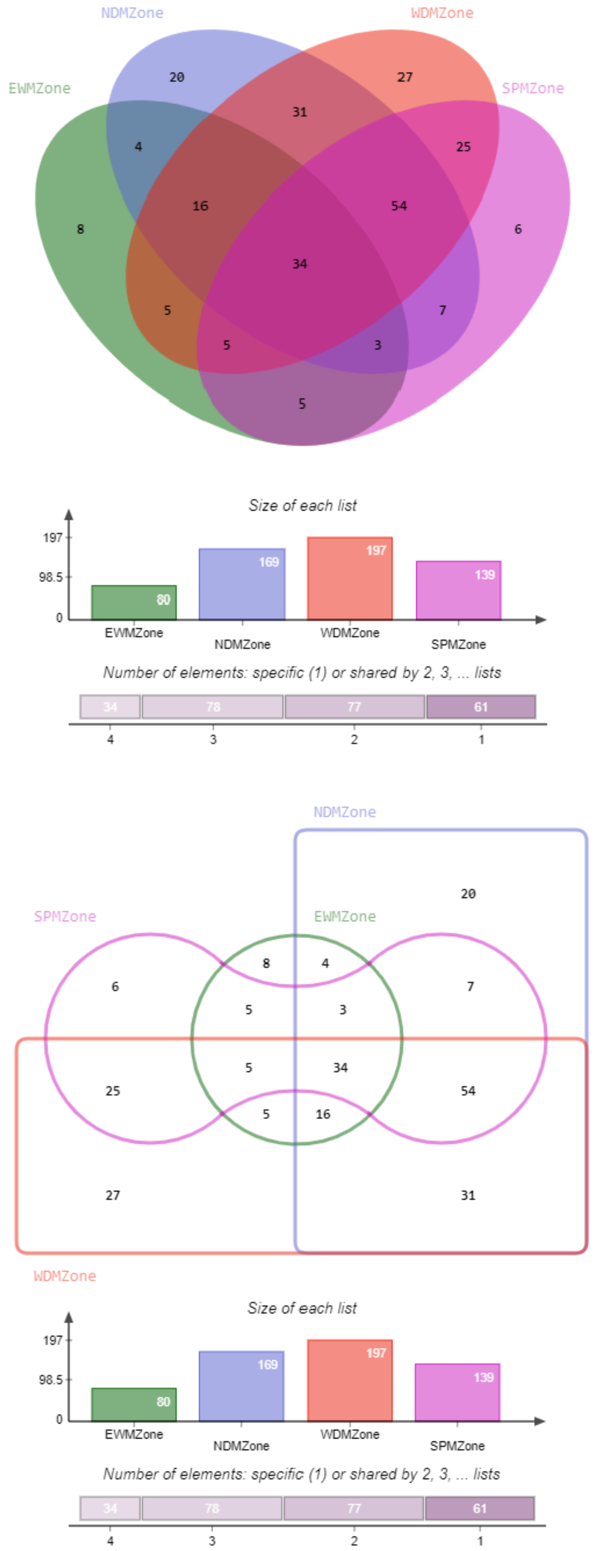


Figure 5.3.16 Venn diagram of plant species across different zones of the study area

5.4 DISCUSSION

Nannorrhops ritchieana has a broad ecological amplitude starting from the xeric environments in Kirthar and D I Khan and finally reaching the cold moist temperate regions of Kurram and Abbottabad. It is a gregarious palm species that forms different associations across several climatic zones from arid to cold environments in Pakistan. The current study documented 251 plant species belonging to 68 families that are associated with *Nannorrhops ricthieana* across different climatic zones. Poaceae is the family with the most associated species (31), followed by Fabaceae (25), Asteraceae (24), Lamiaceae (20), Boraginaceae (12), and Amaranthaceae (12). The remaining families have less than 10 species each that are associated with the palm. Here a question is arising to why Poaceae, Fabaceae, Asteraceae, Lamiaceae, Boraginaceae and Amaranthaceae were the dominant families in the association of *Nannorrhops*. According to Gibson (2008), ecologically Poaceae family is very dominant an estimated 40% of terrestrial ecosystems are covered by grasslands and bamboo forests. Grasses have a great capacity to adapt to various climatic zones. One of the most successful characteristics is the production of many seeds. Asteraceae is also one of the most successful plant families in the world. It has more than 23.000 species distributed all over the world except Antarctica (Jeffery, 2007). One of the significant characteristics of the family is its specialized inflorescence – the capitulum – which attracts insects (Broholm *et al*., 2008). Another important characteristic of the family is the production of lightweight seeds, which can disperse easily from one ecological zone to another such as is the case in *Taraxacum*, *Sonchus*, and *Lactuca*, etc. Fabaceae is the third largest family in the flora of Pakistan (Jahan *et al*., 1994) with 104 genera and 514 species (Ali, 1977). It has a great survival rate. It prefers mostly sandy and loamy soil. Species of this family have nitrogen-fixing bacteria in root nodules which help them in nitrogen fixation. The sandy and loamy soil is crucial for Fabaceae species to help their roots in gaseous exchange. The Khyber Pakhtunkhwa is an important and model habitat for their distribution. Most species of the Fabaceae are therophytes that cope with harmful climatic conditions by overwintering their perinnating buds in the form of seeds (Lubbe and Henry, 2020). Lamiaceae is also an important family having great adaptations to various climatic zone. In Pakistan, it is represented by 65 species mostly consisting of medicinal plants. Most of the species are of Mediterranean origin. However, a few species of Boraginaceae are quite common in the dry habitats of southern parts of the study area such as *Heliotropium europaeum*, *Chrozophora tinctoria*, *Heliotropium muelleri*, *Euploca* *strigosa*. On the other hand, *Cynoglossum lanceolatum, Nonea pulchella, Trichodesma indicum, Decalepidanthus parviflorus,* and *Onosma hispida* are common in the northern dry mountains zone. Their diaspores are dispersed by different modes into different regions (Chacon *et al*., 2017) and they have great potential for survival. Amaranthaceae is also a dominant family in the study region mostly comprised of weeds. *Alternanthera pungens* species of this family have invasive nature and are distributed in different areas mostly along roadsides, or field banks. Some species produce seeds with a spinous sticky nature and might be easily dispersed by animals. *Amaranthus retroflexus* and *Chenopodium album* are cosmopolitan and problematic weeds that inhabit a variety of habitats (Eslami and Ward, 2021; Khan *et al*, 2022).

The classification analysis of plants across 508 plots and 63 populations in the study area revealed a clear division into four different associations. The target species *Nannorrhops ritchieana*is associated with 251 plant species that occur in different types of vegetation across various zones in the study area. Each association had an almost homogeneous species composition. *Nannorrhops ritchieana* provides suitable conditions for its associated plants. Its cushion or patchy type of aggregations, dense vegetation cover, appropriate soil depth and wind resistance are the important characteristics through which it safeguards its associated species. It is an important key functional element of the forest ecosystem (Abdullah *et al*., 2020) like other palms. Other palms also form patches, dense clusters, cushions, or associations such as *Sabal palmetto* in southeastern Mexico (Lopez and Dirzo, 2007), *Mauritia flexuosa* in the Amazon basin (Kahn and de Granville, 1992), *Lepidocaryum tenue* in Amazon (Balslev *et al*., 2010). Palm species' coexistence and the mechanisms involved in their assembly in communities have been disentangled (Svenning 2001; Svenning *et al*., 2008; Bjorholm *et al*., 2008; Eiserhardt *et al*., 2011). *Nannorrhops ritchieana* grows in different areas with different geochemistry and climatic conditions. Other authors also reported that palm species are linked to different environmental factors. Non-climatic factors such as soil, land use, and topography are believed to be crucial factors that control palm distribution, diversity, and composition (Pearson and Dawson, 2003; Jones *et al*., 2006; Eiserhardt *et al*., 2011).

We recorded the highest concentration of magnesium and calcium in different regions where *Nannorrhops ritchieana*grows. These findings corroborate those of Naseem *et al*. (2005) who documented that *Nannorrhops ritchieana*is a magnesium flora. Few American palm species are linked with soil variables i.e., clay texture, aluminum content and other nutrients concentration (Svenning, 2001) which is quite like our results.

We identified three indicator species for each association i.e., a tree, a shrub and an herb by their indicator and p* values using indicator species through PC-ORD software. *Pyrus psuedopashia*, *Daphane mucronata* and *Androsace rotundifolia* are the indicators of the 1st association in the eastern wet mountains zone identified in relation to different environmental gradients, particularly to climatic gradients. *Melia azedarch*, *Rydingia limbata*, *Verbascum thapsus* are the indicators of the 2nd association in the northern dry mountains zone. *Melia azedarach* is identified as an indicator of seven different environmental variables and the remaining two are also strong indicators of the northern dry mountains in the Himalayan range. *Melia azedarach* is mostly debarked by rabbits, goats, sheep, porcupines, and brown bears in the region. The dense vegetation of *Nannorrhops ritchieeana* provides shelter and safeguards it from these herbivores. Therefore, *Melia azedarch* individuals can be accessed in the vicinity where *Nannorrhops ritchieeana* grows. *Capparis decidua*, *Periploca aphylla* and *Convolvulus prostrata* are the indicators of western dry mountains. Their specialized morphology makes them fit for adaptation and survival in these dry habitats in association with *Nannorrhops ritchieeana*. *Phoenix dactylifera*, *Rhazya stricta,* and *Aerva javanica* are the indicators of the Sulaiman Piedmont zone. It is relatively drier than the other zones of the study region. These species are identified as indicators of this zone due to their strong relationships with maximum temperature, lower humidity level and maximum wind speed. This zone has a xeric type of vegetation, and these species are more common.

Other people also identified different plant associations, zonation and communities using the same statistical techniques and tools (Khan *et al*., 2016; Ahmad *et al*., 2016; Bano *et al*., 2018; Iqbal *et al*., 2018; Khan *et al*., 2020, Rehman *et al*., 2020; Neil *et al*., 2020; Mumshad *et al*., 2021; Haq *et al*., 2021; Manan *et al*., 2021; Ahamd *et al*., 2022; Anwar *et al*., 2019; Ahmad *et al*., 2023). Floristic homology across different zones was tested using the Venn diagram following Khan *et al*. (2019) and Rehman *et al*. (2020). The EWM zone had less uniqueness in their plant (only four species) due to the lower number of sampling plots. The NDM zone had 20 unique species. It had more diversity in topography and environmental factors. The WDM zone has 27 unique species and mostly the uniqueness was due to Kurram and Orakzai valley, which is an important region in terms of plant diversity characterized by a cold climate. It is surrounded by the drier regions of Hangu, Waziristan, Kohat, and Khyber and hosts unique plant diversity. The SPMZone is the driest zone hosting six unique species from the remaining three zones.

5.5 CONCLUSIONS

It is crucial to understand how linkages and associations developed among plant species with environmental factors in the surrounding ecosystem. We chose the *Nannorrhops ritchieana*, a gregarious palm that forms different associations across climatic zones from arid to cold environments across 63 transects (508 plots). A total of 251 plant species in four different associations were recorded and then we identified three indicator species for each association. Association 01 indicators were *Pyrus pseudopashia*, *Daphne mucronata*, and *Androsace rotundifolia*, association 02 indicators were *Morus alba*, *Rydingia limbata*, and *Physalis peruviana*, association 03 indicators were *Capparis decidua*, *Periploca aphylla*, and *Aerva javanica*, association 04 indicators were *Phoenix dactylifera*, *Rhazya stricta*, and *Aerva javanica* based on the indicator and p* values. We conclude that *Nannorrhops ritchieana*, being a gregarious and charismatic palm species, prefers to live in different associations under the influence of various climatic drivers in the Khyber Pakhtunkhwa province. The species has diverse types of associations controlled by various sorts of climatic factors. This research work will be a model approach for the identification of different plants' associations with climate.

CHAPTER 06

Seed dormancy and germination in *Nannorrhops ritchieana* (Griff.) Aitch.

6.1 INTRODUCTION

Understanding seed dormancy and germination is very important for plant conservation and propagation. It is a key contemporary question that how various environmental factors limit and control seed dormancy and germination. Temperature, humidity, drought, light duration salinity, soil pH, fire, seed burial depth and flooding play an important role in the initiation and inhibition of seed germination (Baskin and Baskin, 2014; Cuneo *et al*., 2010; Humphries *et al*., 2018).

Temperature and humidity are crucially important environmental factors in the regulation of seed germination (Bewley *et al*., 2014). These factors affect the percentage, speed and time from seed dispersal to germination in various plant species (Guo *et al*., 2020). It directly controls the mechanism of imbibition and seed metabolism that regulates seed biochemical reactions involved in germination (Filho, 2015). Seed dormancy mostly arises in plants due to underdeveloped embryos, hard seed coats and unsuitable environmental conditions (Abubakar and Attanda, 2022). The phenomenon of underdeveloped embryos and hard seed coats is very common in the family Arecaceae (Baskin and Baskin, 2014; Jaganathan, 2021). It has been assessed that palm species have a germination rate of less than 20% (Meerow and Alan, 2004). On the other hand, more than 25% of palm species require over 100 days to germinate (Tomlinson, 1990). The bulk of a palm seed is taken up by nutritive tissue called endosperm that provides food for the germinating seedling for a longer period than most other flowering plants (Meerow, 2004). They are idiosyncratic in the process of germination, seed structure and seedling morphology (Medeiros *et al*., 2015; Tomlinson, 2006). Generally, in palm species low germination levels are common and various types of dormancy are reported (Baskin and Baskin, 2004). Some palm species grow in stressful and dry environments (Hazzouri *et al*., 2020). In such environments, slow and irregular germination is an adaptive strategy to cope with stress (Baskin and Baskin, 2004).

Various techniques are used to overcome seed dormancy in palms such as immersion in water (Medeiros *et al*., 2015), hormonal application (He *et al*., 2021), scarification (Pérez *et al*., 2008), cold and warm scarification (Yang *et al*., 2007; Jaganathan *et al*., 2021), removal of operculum (Ribeiro *et al*., 2011; Neves *et al*., 2013) and many others.

*Nannorrhops ritchieana*also faces the problem of slow germination. It grows under blazing heat and water scarcity and other stressful conditions across Oman, Afghanistan, Iran, and Pakistan and in different areas of Sindh, Baluchistan and Khyber Pakhtunkhwa (Abdullah *et al*., 2020).

Moreover, the species takes a long time to reach maturation which is another bottleneck for its propagation and conservation. It takes 25-40 years to reach maturation. The dispersal is mainly by birds and mammals, and therefore, it has a sporadic distribution and the populations are mostly made up of juvenile and mature individuals, while seedlings are very rare in their native geographic range (Abdullah, 2019) due to stressful environmental conditions and continuous grazing pressure. The species has hard-dried seeds ranging from 10–13mm in size (Moricca *et al*., 2020) with the adjacent type of seed germination (Henderson, 2006). Lackner (2003) writes about *Nannorrhops ritchieana* "I keep the seeds at temperatures between 30 and 45°C as these hot temperatures are necessary for good results". *Nannorrhops ritchieana* propagates by seeds only, which are dormant under inapt environmental conditions.

On the other hand, the dramatic increase in human population, several uses and applications, uprooting by animals, and highway constructions are major and chronic challenges that wipe out its population (Gibbson and Spanner, 1995; Nabi *et al*., 2017). During our experimentation for the last four years on *Nannorrhops ritchieana* seed ecology, we observed vigorous germination under 35–45°C temperature and maximum humidity in the glass house of the botanical garden Quaid-i-Azam University Islamabad Pakistan. We also observed that the species did not respond to growth hormones (Indole acetic acid, gibberellic acid, and indole butyric acid) under cold environmental conditions.

We hypothesized that *Nannorrhops ritchieana* seed germination is controlled by optimum temperature and humidity. Therefore, it is essential to understand the seed biology of *Nannorrhops ritchieana* and address the question of slow germination caused by temperature and humidity, which is crucial for its conservation and propagation under the existing environmental conditions. The objectives of this study were (1) to know the impact of H2SO4, HNO3, Thiourea, Hot water treatment, GA3 and IAA in different concentrations and immersion times. (2) Understand the temperature and germination relationship by monthly observations of germination in all experiments.

6.2 MATERIALS AND METHODS

6.2.1 Nannorrhops ritchieana seed collection

Mature fruits of *Nannorrhops ritchieana* were collected from different regions of D I Khan (Gilloti, Abdulkhel, Rehmani Khel and Paniala) in October 2019. The climate of D I Khan is arid-subtropical. The average climate data between 1970 and 2010 show that the average winter temperature ranges from 14.3—22.5˚C while the average summer temperature ranges from 24.8—40.5 ˚C. The average annual winter precipitation ranges from 27.46—115.4 mm (Hussain *et al*., 2013). December and January are the coldest months while June and July are the warmest period of the year. The region has xerophytic vegetation. *Capparis decidua*, *Periploca aphylla*, *Periploca callophyla*, *Acacia nilotica*, *Prosopis juliflora*, *Phoenix dactylifera*, and *Nannorrhops ritchieana* are the dominant plants in the region. The region is an important habitat for *Phoenix dactylifera* and *Nannorrhops ritchieana* fruit production due to its warm climate. *Nannorrhops ritchiena* fruits ripen in August and September and are consumed by birds and local people in the region (Marwat *et al*., 2011). Fruits were transferred to the Ecology and Conservation Lab Quaid-i-Azam University, Islamabad and kept at room temperature.

After 25 days of the arrival at the laboratory, the dried flesh exocarp was removed carefully without triggering harm, so as not to impede seed germination vigor and potential and stored in polythene bags at a room temperature (24± 3°C, and 45—65RH).

Seeds were disinfected with sodium hypochlorite (NaClO) for 20 minutes followed by thorough washing with distilled water before experimentations. A randomized complete block design was used during this study, each treatment was comprised of four replicates of ten seeds (total 40 seeds). The experimental setup was done in the botanical garden of Quaid-i-Azam University Islamabad, Pakistan. The experiment was monitored to document the number of germinated seeds after 24-hour intervals for a year. The criterion for seed germination was the emergence of the radicle (Zardari *et al*., 2019).

6.2.3 Experimental design

6.2.3.1 Effect of acids scarification on germination

Seeds stored at 25˚C were treated with 5, 10 and 15% concentrated H2SO4 and HNO3 solutions for 6, 12, 18, and 24 hours. After treatment with acids seeds were properly washed with distilled water. Seeds were placed in polythene bags containing loamy soil and humidity was maintained by proper irrigation.

6.2.3.2 Thiourea treatment

Seeds were immersed in 50mg/L, 100mg/L, and 150mg/L solutions for 24, 48, and 72 hours. After treatment with thiourea seeds were properly washed with distilled water. Seeds were placed in polythene bags containing loamy soil and humidity was maintained by proper irrigation.

6.2.3.3 Effect of GA3 and IAA on seed germination

Four replicates of ten seeds for each treatment of 1000, 2000 and 3000mg/L solution of GA3, and IAA (Sigma-Aldrich, St. Louis, USA) as used by (Neves *et al*., 2013; Ribeiro *et al*., 2011; Dias *et al*., 2013; Mazzottini-dos-Santos *et al*., 2018) for 24, 48, and 72 hours intervals modified from the study of Medeiros *et al* (2015) on *Syagrus coronata*. After treatment seeds were transferred in polythene bags containing loamy soil and humidity was maintained by proper irrigation.

6.2.3.4 Hot water treatment

Seeds were immersed in the water bath at 35 °C, 40 °C and 45°C for five, ten, and 15 days. After treatment seeds were transferred in polythene bags containing loamy soil and humidity was maintained by proper irrigation.

6.2.3.5 Data analysis

We gathered data from field book sheets in MS Excel. Germination indices such as Germinated seeds (grs), germinability (grp), mean germination rate (mgt), germination speed (gsp), uncertainty Index (unc), synchronization index (syn), germination variance (vgt), germination standard deviation (sdg) and coefficient of variation (cvg) were determined through germinaQuant application of GerminaR package through R-programming. We tested the results for all treatments through ANOVA with a posthoc Tukey test on significance ($P < 0.05$) within tested variables. In the ANOVA tables, 0.001 significance was represented by (***), 0.01 by (**) and 0.05 by (*). Data visualization was carried out with the GerminaR package (Lozano-Isla *et al*., 2019) using germinability (grp) as the response variable and treatment (chemical concentration) and immersion time were the explanatory variables

6.3 RESULTS

6.3.1 Scarification with H2SO4

The highest 80% germination percentage (grp) was observed in seeds treated with 5% H2SO4 for six hours. A gradual decrease was observed in grp with an increase in immersion time and acids concentration. In seeds treated with 5% acids for 12 hours 75%, 5% acids for 18 hours 70%, and 5% acids for 24 hours 62.5% grp was recorded. The lowest grp (20%) was recorded in seeds treated with 15% acids for 24 hours. On the other hand, 52.5% germination was observed in the control (Figure 6.1, Appendix 6.1). Our ANOVA table shows that H2SO4 and Time both have a significant impact with (Pr(>F) = 2e-16***) and (Pr(>F) = 7.25e-05***) respectively while both the factors H2S04~Time in combination have no significant impact (Pr(>F) = 0.83) on the response variable (Table 6.1).

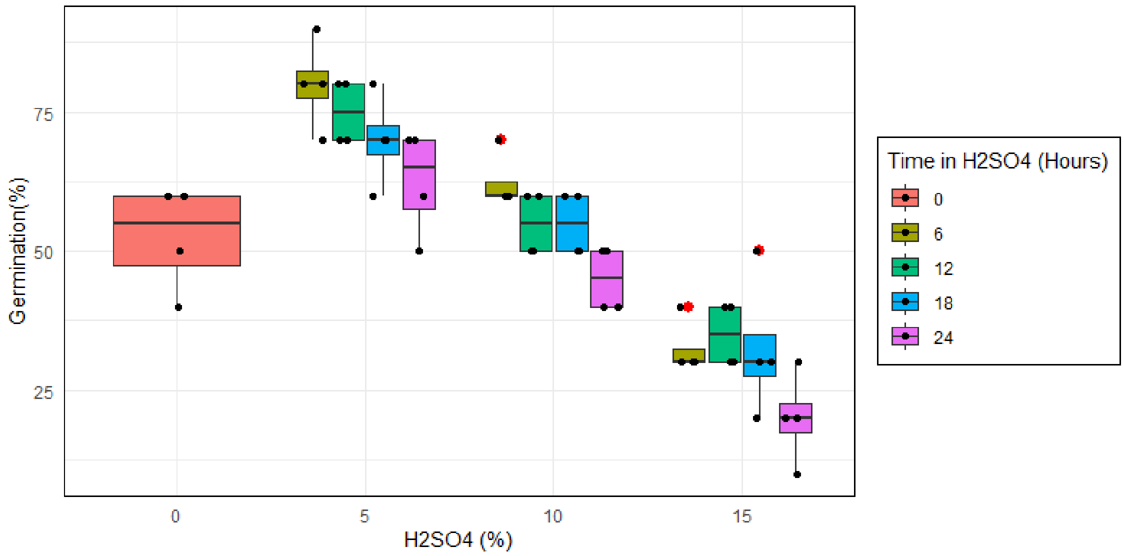


Figure 6. 3.1 Germination percentage of *Nannorrhops ritchieana* treated with different concentrations of H2SO4

Table 6.3.1 ANOVA table of H2SO4 treatments

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
H2SO4	3	14155	4718	80.885	< 2e-16 ***
Time	3	1675	558	9.571	7.25e-05 ***
H2SO4:Time	6	163	27	0.464	0.83
Residual	39	2275	58		

6.3.2 Scarification with HNO3

HNO3 also showed a similar trend to that of H2SO4. As with an increase in concentration and time a gradual decrease was observed in seed germination. The highest 72.5% germination percentage (grp) was observed in seeds treated with 5% HNO3 for six hours. A gradual decrease was observed in grp with the increase in immersion time and acids concentration. In seeds treated with 5% acids for 12 hours 67.5%, 5% acids for 18 hours 62.5%, and 5% acids for 24 hours 65% grp was recorded. The lowest grp (27.5%) was recorded in seeds treated with 15% acids for 24 hours. On the other hand, 52.5% germination was observed in the control (Figure, 6.2, Appendix, 6.2). Our ANOVA table indicates that exploratory variables HNO3 and Time both have a significant impact with (Pr(>F) = 2e-16***) and (Pr(>F) = 2.38e-06***) respectively while both the factors HNO3 ~Time in combination have no significant impact (Pr(>F) = 0.818) on the response variable (Table 6.2).

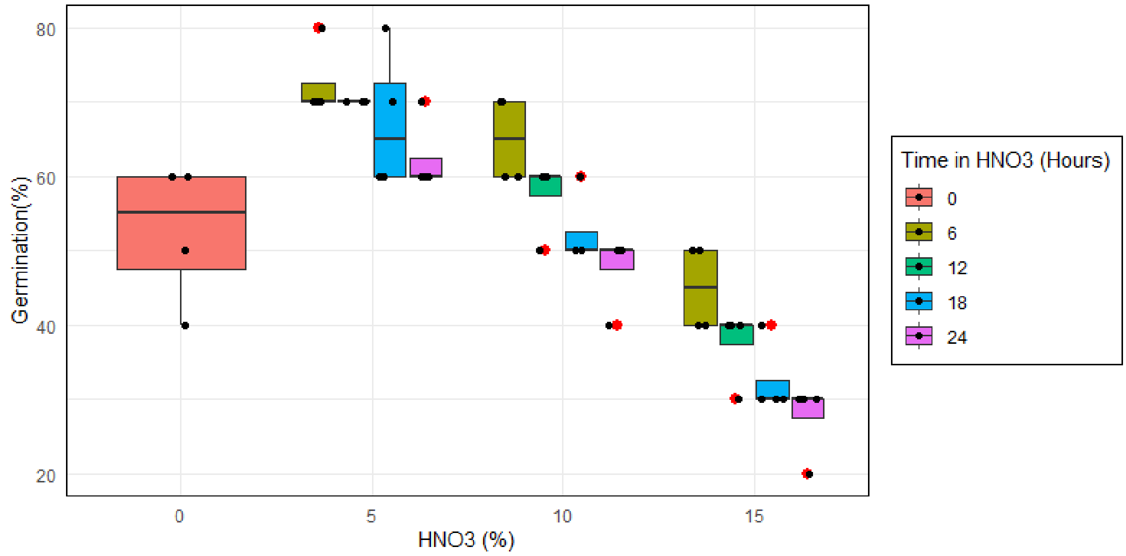


Figure 6.3.2 Germination percentage of *Nannorrhops ritchieana* treated with different concentrations of HNO3

Table 6.3.2 ANOVA table of HNO3 treatment

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
HNO3	3	8601	2867.1	82.829	< 2e-16 ***
Time	3	1456	485.4	14.023	2..38e-06 ***
HNO3 :Time	6	100	16.7	0.481	0.818
Residual	39	1350	34.6		

6.3.3 Stratification with hot water

In the hot water treatment experiment we observed that the percentage of seeds germinating significantly increased from control (55%) to 75%, 72.5%, and 72.5% in 5% concentration for five days of immersion in water at 35$^{\circ C}$, 40$^{\circ C}$ and 45$^{\circ C}$ respectively. A small decrease in grp was observed with immersion time from five to ten 5–15 days i.e., 70%, 72.5%, and 72.5% at 35$^{\circ C}$, 40$^{\circ C}$ and 45$^{\circ C}$ respectively. Interestingly, with an increase in immersion time from 10–15 days grp reached 85%, 85%, and 82.5% at 35$^{\circ C}$, 40$^{\circ C}$, and 45$^{\circ C}$ respectively (Figure 6.3, Appendix 6.3). The ANOVA table shows that exploratory variables hot water treatment and time both have a significant impact with (Pr(>F) = 4.71e-05***) and (Pr(>F) = 0.000262***) respectively while both the factors hot water treatmnet ~time in combination has no significant impact (Pr(>F) = 0.907675) on the response variable (Table 6.3).

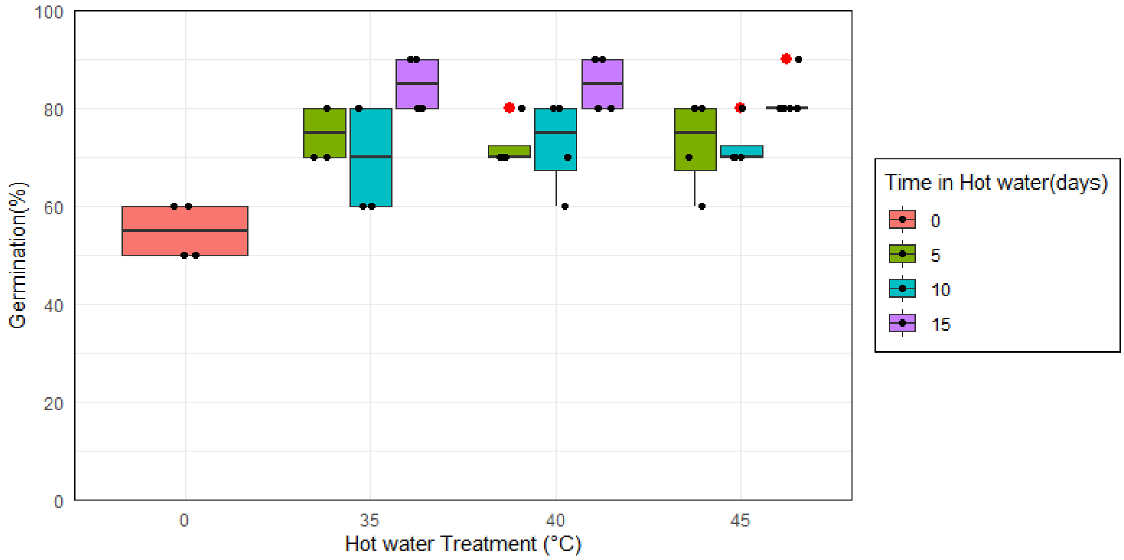


Figure 6.3.3 Germination percentage of *Nannorrhops ritchieana* treated with water at different temperatures

Table 6.3.3 ANOVA table of hot water treatments

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
HWT	3	1668.7	556.2	10.91	4.71e-05 ***
Time	2	1110.1	555.1	10.89	0.000262 ***
HWT: Time	4	50.9	12.7	0.25	0.907675
Residual	31	1580.0	51.0		

6.3.4 Effect of GA3 on germination

Seeds treated with GA3 showed a direct effect on seed germination. With the increase in concentration and time a continuous increase was observed in seed germination. Seeds treated with 1000 mg/L GA3 solution for 24, 48, and 72 hours intervals showed grp of 70, 72.5, and 82.5%, while seeds treated with 2000 mg/L GA3 solution for 24, 48, and 72 hours intervals showed 77.5, 72.5, and 82.5% grp. Moreover, seeds treated with 3000mg/L solution of GA3 for 24, 48, and 72 hours intervals showed 75, 77.5, and 87.5% grp. In all treatments, germination was significantly higher than control (52.5%) (Figure 6.3.4, Appendix 6.4). The ANOVA results indicate that GA3 and different time intervals significantly influence seed germination (Pr(>F) = 0.000134***) and (Pr(>F) = 0.015538*) respectively while both the factors GA3~Time in combination have no significant impact (Pr(>F) = 0.875609) on the response variable (Table 6.3.4).

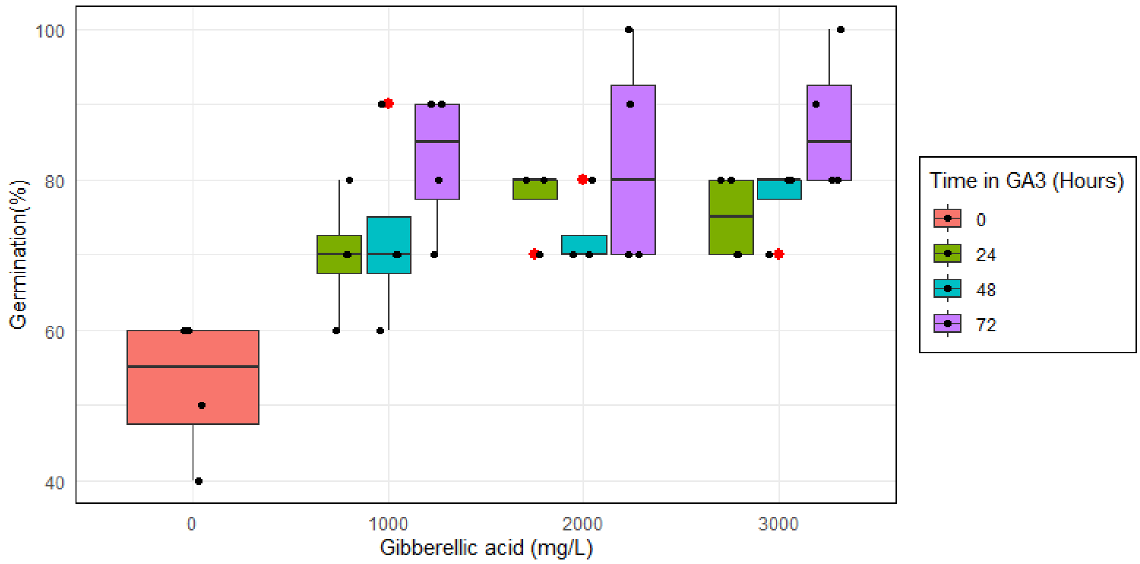


Figure 6.3.4 Germination percentage of *Nannorrhops ritchieana* treated with GA3

Table 6.3.4 ANOVA table of GA3 treatments

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GA3	3	2400	800.0	9.6	0.000134 ***
Time	2	800	400.0	4.8	0.015538 *
GA3: Time	4	100	25.0	0.3	0.875609
Residual	30	2500	83.3		

6.3.5 Effect of IAA on germination

We recorded a considerable increase in seed germination treated with IAA compared to the control (52.5%). But there is no significant relation impact of different time intervals. Seeds treated with 1000 mg/L IAA solution for 24, 48, and 72 hours intervals showed grp of 72.5, 67.5, and 75%, while seeds treated with 2000 mg/L IAA solution for 24, 48, and 72 hours intervals showed 70, 72.5, and 72.5% grp. Moreover, seeds treated with 3000mg/L solution of GA3 for 24, 48, and 72 hours intervals showed 75, 77.5, and 77.5% grp (Figure 6.3.5, Appendix 6.5). The ANOVA results indicate that IAA concentration has a significant impact on grp (Pr(>F) = 1.07e-05 ***), while time intervals had no influence (Pr(>F) = 0.574). IAA and time in combination are also factors not influencing grp in a significant way (Pr(>F) =0.689 (Table 6.3.5).

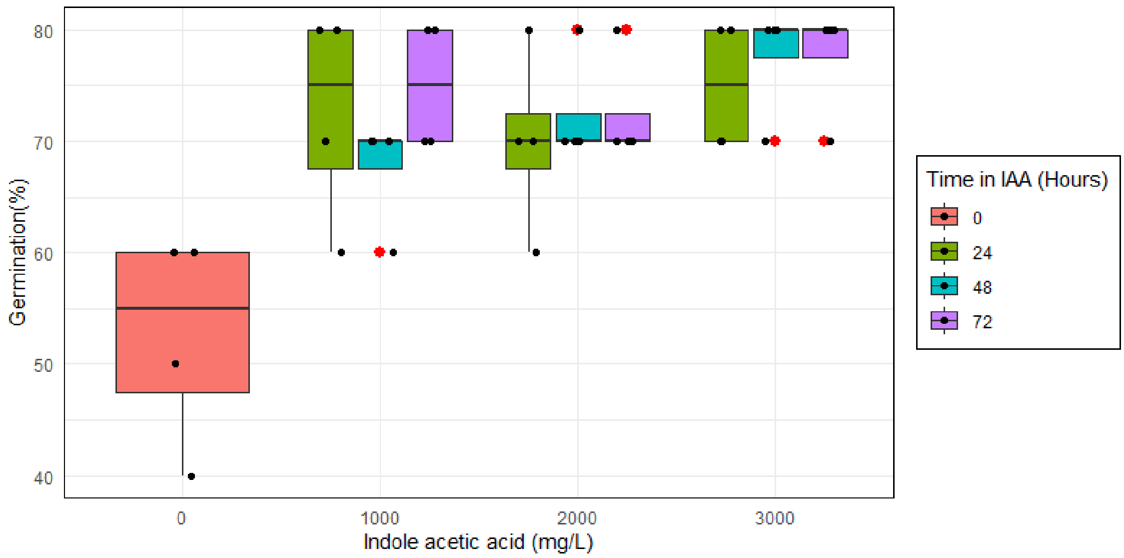


Figure 6.3.5 Germination percentage of *Nannorrhops ritchieana* treated with IAA

Table 6.3.5 ANOVA table of IAA treatment

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
IAA	3	1762	587.5	13.302	1.07e-05 ***
Time	2	50	25.0	0.566	0.574
IAA:Time	4	100	25.0	0.566	0.689
Residual	30	1325	44.2		

6.3.6 Effect of thiourea on germination

Our results showed that 1gram thiourea solution with 24 hours immersion time significantly affected the seed germination and the grp reached 72.5, followed by two-gram thiourea solution with 24 hours immersion time (70%) and one-gram thiourea solution with 72 hours immersion time with 62.5 grp. The lowest grp was recorded for seeds treated with 0.2 (40%) and 0.2 (40%) gram thiourea for 48 hours (Figure 6.6, Appendix 6.6). The ANOVA table reveals that exploratory variables Thiourea and time both have a significant impact on grp with (Pr(>F) = 0.00184**) and (Pr(>F) = 6.69e-05***) respectively while both the factors thiourea~time in combination have no significant impact (Pr(>F) = 0.40642) on the response variable (Table 6.6).

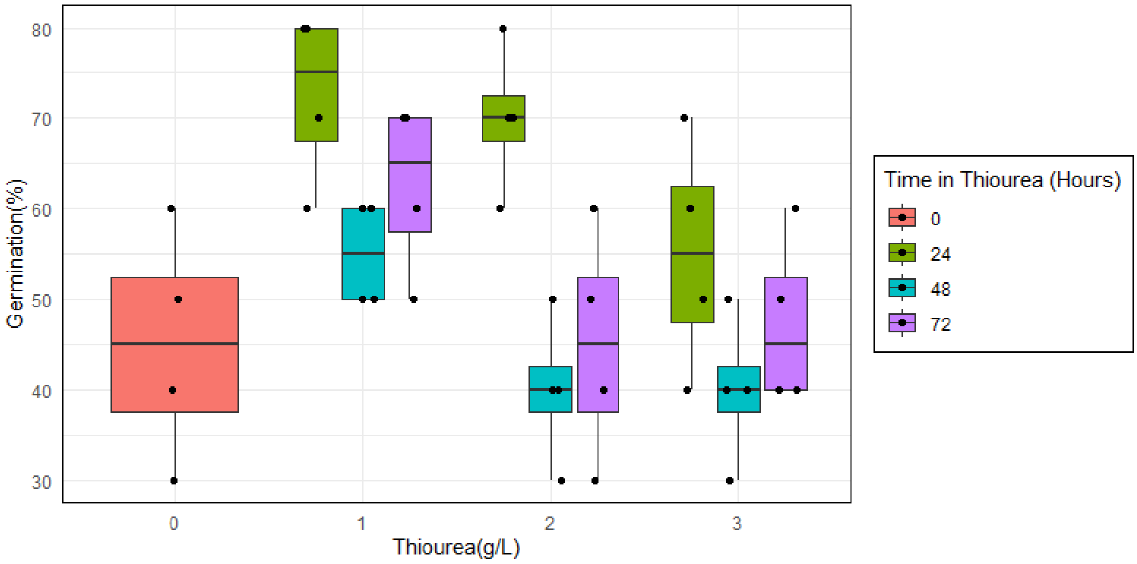


Figure 6.3.6 Germination percentage of *Nannorrhops ritchieana* treated with thiourea

Table. 6.3. 6 ANOVA table of thiourea treatments

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Thiourea	3	1919.2	639.7	6.344	0.00184 **
Time	2	2716.7	1358.3	13.471	6.69e-05 ***
Thiourea:Time	4	416.7	104.2	1.033	0.40642
Residual	30	3025.0	100.8		

6.4 DISCUSSION

Palm species have a hard pericarp which is impermeable to water (Carpenter *et al*., 1993; Moussa *et al*., 1998; He *et al*., 2021) and for cultivation, their seeds are mostly treated with mechanical or chemical scarification. Our findings show that chemical scarification with H2SO4 and HNO3 improve seed germination up to 80% and 72.5 % respectively at the lowest 5% concentration with six hours of immersion time. But with an increase in concentration to 10% and 15% a gradual decrease was observed. The species' hard seed coats create problems in seed germination due to the impermeability of water and oxygen (Abdullah *et al*., 2022). Scarification with H2SO4 and HNO3 improves seed germination but an increase in acid concentration and immersion time causes a negative impact, probably because it obliterates the seed embryos resulting in the lowest grp of 20% as recorded in 15% acids concentration while the control was 52.5%. We conclude that acid scarification with a 5% concentration ruptures the seed coat and improves impermeability but a further increase in concentration destroys the embryo and triggers seed germination. Our results corroborate with the results of (González-Benito *et al.*, 2006) who studied seed germination and storage in the *Chamerops humilis* palm. They recorded that an increase in acid concentration causes harm to the embryo and hence seed germination decreases.

Thiourea is also used to enhance seed germination in palms (Ravichandran *et al*., 2016). In our study, maximum seed germination was recorded in seeds treated with 1-gram thiourea solution while the lowest grp was recorded for seeds treated with 0.2-gram thiourea solution.

We also experimented with hot water at 35$^{\circ C}$, 40$^{\circ C}$ and 45$^{\circ C}$ temperatures for five, ten, and fifteen days. Our findings in this experiment showed that seed germination increased with hot water treatment for five days compared to the control while in ten days of treatment, a little decrease was observed and again an upsurge was recorded in seeds kept for 15 days. The germination pattern was inconsistent with an increase in days exposed to hot water treatment. The seeds used in this experiment were collected from similar regions and stored in one pot in the experimental room of Plant Ecology and Conservation Laboratory. To understand the impact of hot water on seed germination further experimentation is needed. Moreover, various concentrations of GA3 showed a direct effect on seed germination, with the increase in concentration and time a continuous increase was observed in seed germination. Seeds treated with 1000, 2000, and 3000mg/L solution of GA3 for 72 hours intervals showed 82.5, 82.5, and 87.5% grp which is higher than other treatments and control. We conclude that an increase in GA3 concentration and immersion time causes a considerable increase in seed germination probably by promoting the growth potential of the embryo (He *et al*., 2021). The application of GA3 makes the embryo stout to overcome the resistance of the operculum and micropyle endosperm (Baskin and Baskin, 2014). On the other hand, our findings for IAA show a considerable increase in seed germination at various concentrations compared to the control (52.5%). But there is no significant impact of different time intervals on seed germination (Figure 6.5 and Table 6.5). We elucidate that IAA initiates seed germination irrespective of immersion time.

Throughout these studies, we noticed a strong linkage between seed germination and temperature. The seeds did not germinate in Pakistan until March. We started all these experiments in October 2019 and seed germination began in the following April. In Pakistan, winter starts in November and ends in March. In March few seeds germinated, in April, then in May, and in June the numbers increased. In July the maximum number of seeds germinated in all experiments and in July in Pakistan temperature ranges from 35–45^{o}C in the Capital. Keeping in view the results of all experimentations elucidate that hard seed coat is a serious problem to its germination. A hot temperature in the summer months is required which might cause cracks in the seed coat of the species, through which water easily penetrates the seed and causes germination. On the other hand, high soil humidity is also mandatory for seed germination. Similar results have been recorded (Lackner, 2003) for *Nannorrhops ritchieana* by recording maximum germination at 35–40^{o}C.

6.5 CONCLUSION

Nannorrhops ritchieana is an important economic species facing many problems because of the slow and low rate of seed germination. To know the complex puzzle of seed germination in *Nannorrhops ritchieana* we have tried to identify suitable and non-laborious methods for seed dormancy alleviation in this economic palm by performing different experimentations. Scarification with H2SO4, HNO3 and thiourea in low concentrations was the best for seed germination but gradually a decrease was observed with an increase in acid concentration. We conclude that an increase in acid and thiourea concentration damages the embryo and triggers seed germination for long time immersion. Moreover, an increase in GA3 concentration and immersion time leads to a significant increase in seed germination while IAA initiates seed germination irrespective of immersion time. These results reveal that the application of GA3 and IAA provides strength to the embryo in germination. Hot water treatment is the best non-laborious and inexpensive treatment causing a significant upsurge in seed germination. An increase in time from 5–15 days and 35–45 ^{o}C temperature caused seed germination. In addition, we observed that in April, May, June, and July a maximum number of seeds germinated. These months correspond to the summer in the capital of Pakistan where the experiments were executed at temperature ranges from 35–45^{o}C. Keeping in view the results of all experimentations we elucidate that the hard seed coat is a serious problem to its germination. The hot temperature in the summer months is required which might cause cracks in the seed coat, through which water easily goes inside and cause germination. On the other hand, high soil humidity is also necessary for seed germination.

Donation of Nannorrhops ritchieana

The *Nannorrhops ritchieana* plants developed during this research project have been distributed to various botanical gardens, institutions, farmers, and students. Some of these plants were planted during different events. The recipients of the plants include:

(i) Habib Botanical Garden, Gomal University, D I Khan
(ii) Botanical Garden, University of Malakand
(iii) Pakistan Museum of National History, Islamabad
(iv) University of Swat, Swat
(v) Pir Mehar Ali Shah, Arid Agricultural University, Rawalpindi
(vi) Mosquito Control Association, led by Shah Fahad
(vii) Government Post Graduate College, Haripur
(viii) Government Post Graduate College, Bajaur
(ix) Zakirullah Farmer, Bajaur
(x) Zahidullah Farmer, Bajaur
(xi) Raja Shahid Gardener, Islamabad
(xii) Abdullah and Professor Anders Sanchez Barfod provided a few seeds of *Nannorrhops ritchieana* to the Aarhus University Botanic Have (garden) for germination and future record

CHAPTER 07

SYNTHESIS

With the information on ecosystem services, socioeconomics, populations, associations with other plants and the problems *Nannorrhops ritchieana* palm faces in the form of overexploitation, population fragmentation and seed germination it becomes possible to draw together the preceding parts, to write a synthesis or general discussion of this dissertation. The intention is to explain the diverse elements of this dissertation in the light of our observations, experimentations and previous knowledge of *Nannorrhops ritchieana* and other palms in one coherent synthesis.

7.1 ECOSYSTEM SERVICES

Nannorrhops ritchieana is a cultural keystone species that provides multiple ecosystem services, i.e., regulating, cultural, provisioning and aesthetic (Abdullah *et al*., 2020). The multiplicity of provisioning ecosystem services makes it more valuable than other plant species and hence difficult to replace by other species. Its fruit is used for food by humans, birds and various other animals. Leaves are an important source of livelihood and socioeconomics in remote areas in Pakistan, Iran, Afghanistan, and Oman (Marwat *et al*., 2011; Marwat *et al*., 2012). They weave various types of handicrafts, i.e., baskets, mats, hats, ropes, brooms, hand fans, bedsteads, hot pots, and many others (Ali *et al*., 2020; Thomas *et al*., 2012; Latif *et al*., 2004). But there was no broad-scale study on various goods and utensils processed of *Nannorrhops ritchieana* leaves. In this dissertation, we gathered data about the use of the species from various regions inhabited by different tribes and casts. There are different ways in which to quantify how different handicraft usages vary among different cultural communities. In the 3rd chapter, we address such questions by using advanced statistical approaches (Figure 3.1) to present a clear image of the relationship between various uses in different traditional communities. We disentangled the fiber dying techniques and the impact of tourism on the business of different handicrafts. In addition, we mentioned its environmental benefits in comparison to natural fibers and the threats faced by the species in its native habitats. Among such factors, high marketability and usefulness are the leading ones that cause intense harvesting and mismanagement of its populations. Keeping in mind the challenges faced by *Nannorrhops* *ritchieana,* we tried to explore its population ecology to present its status across the studied region in Chapter 04 of this dissertation.

7.2 POPULATION ECOLOGY OF *NANNORRHOPS RITCHIEANA*

Population density, dispersal, distribution pattern, age structure, natality, mortality, and the factors that affect its population are the key parameters to be focused on while assessing the species population ecology (Conquet *et al*., 2023), particularly those who face the problem of overexploitation. However, only little is known about the populations of *Nannorrhops ritchieana* across its native range. We also evaluated the species' ecological attributes such as density, cover, and importance value index (IVI) across different zones of the study area.

Density was higher in WDMZ followed by SPMZ. These zones are considered the original and most suitable habitats for the species. One possible reason for the species' higher density records in WDMZ is the role of law or Mazri Control Act 1953 (see the summary of the act in box 7.1) and favorable climatic conditions while in SPMZ the soil is the almost silty type where the species grows well and establishes dense populations. In EWMZ we reported only two populations, mostly dominated by juvenile and young plants. On the other hand, the NDMZ has less population density with higher cover records than other zones with a sporadic type of distribution. Moreover, IVI is the sum of relative density, relative cover, and relative frequency divided by three which vary across different regions. In some cases, plants with lower densities may grow better with high canopy cover than those with higher densities (Feldman *et al*., 2011).

In natality data, we only recorded 119 seedlings across the whole region, which is less than other age groups. The low number of seedlings indicates that it will be difficult for seedlings to cover the gap of other individuals that die or face the problem of death due to multiple abiotic and biotic factors. The main problem of seedling conservation is grazing pressure. The seeds are dispersed by birds or other animals (Sayedi *et al*., 2022). After germination, they are mostly eaten by goats and sheep or uprooted by porcupines or black bears which is a serious threat not only to seedlings' conservation but to other age classes as well (Abdullah *et al*., 2019). On the other hand, old individuals are mostly conserved in graveyards because of the respect and sacredness and sanctity of graveyards (Abdullah *et al*., 2021).

However, we for the 1st time reported that the Indian crested porcupine and the black bear uproot the species and cause a considerable loss to its population. In interviews, we record from local people (most of them shepherds) that *Nannorrhops ritchieana* roots are a preferred food and feast of the porcupine population. Our findings show that with the decrease in the population of *Nannorrhops ritchieana* the porcupine population is also decreasing in different regions of the study area. Uprooting by these animals is another serious problem that causes species mortality in the region.

Leaf harvesting in an improper time and mismanaged way is another bottleneck for its conservation and sustainable use. The harvesting period ranges from October to February. Children mostly pull the main shoot/ palm hearts to use them as raw food which leads to species mortality. According to our results, a total of 172 stumps were recorded from different zones, of which 69 were from WDMZ followed by SPMZ 65 (Figure 5.7). In both zones, we recorded various threats but the most prevalent one was road construction and being crushed by vehicles. During our survey in WDMZ, the search for oil and gas was continuous while in SPMZ China Pakistan Economic Corridor (CPEC) was under construction where they crushed and uprooted many palm individuals. CPEC is a serious threat to the conservation of biodiversity in northern Pakistan (Nabi *et al*., 2017; Lashari *et al*., 2020). In EWMZ the species population in Mansehra faces extinction and very few individuals remain and, if the construction activities continue, in a few years the population will be diminished. In NDMZ only 22 stumps were recorded of which most of them were uprooted by porcupines. In Hindukush valleys (NDMZ) people care for the species for their household usage and some cultivate the species on the bank of their agricultural fields and hence in this way, it is conserved. On the other hand, graveyards were also conservation hotspots in the region.

But unfortunately, during the last two decades, the province of Khyber Pakhtunkhwa has been confronted with instability and insurgency (Khan *et al*., 2012; Muazmmil *et al*., 2021). The military of Pakistan carried out operations against the invaders to maintain stability and peace in the region. They conducted several operations in different regions, i.e., Bajaur, Mohmand, Khyber, Orakzai, Kurram, North as well as South Waziristan. The insurgencies not only affected the education and livelihood in the region but also devastated many plant species. Graveyards flora due to their sacredness and sanctity are mostly not disturbed by anthropogenic activities. The dense vegetation of graveyards functioned as a shelter for the insurgents, and they dug foxholes. After a few attacks on the army, they cleared the vegetation of graveyards and at a 200-meter distance along the roadside (Suleri *et al*., 2016) to get rid of these hideouts. In the course of these operations, *Nannorrhops ritchieana* and many other trees were eliminated (Abdullah *et al*., 2022). In some regions, the graveyards still host old individuals of the species. We observed that the plant height controls the fruit ecology of the species.

In trees, fruit ecology can be influenced by different factors such as tree size and soil nutrient acquisition and availability (Minor and Kobe, 2019). The hypothesis of Minor and Kobe, (2019) states that “Fruit production will increase with nutrient availability”. In Chapter 04, we evaluated the impact of plant height and fruiting ecology. We found that plant height (age) controls different traits, i.e., size, fruit number, fruit size and seed size. Inflorescence size, fruit number, and fruit and seed size are their maximum in middle-aged palms, followed by young and then decreases in old plants (Figure 5.8, Figure 5.9, Figure 5.10). We assume that the species' fruiting ecology might be related to its nutrient acquisition capacity. Plants at a young age might absorb less quantity of nutrients compared to mature plants and more than old plants because they are stout and stronger than old plants. Therefore, young individuals have a lower output in terms of fruit production compared to mature and higher than old plants. A study on the fruiting ecology of *Mauritia flexuosa* in the Peruvian Amazon reported that with the increase in height, an increase occurs in its fruit number and volume (Romulo *et al.*, 2022). Their results are opposite to our findings. The difference in the fruiting ecology may be due to variations in geographic locations and associated vegetation. They also mentioned that with the increase in height, the plant captures more sunlight which results in higher seed production. But *Nannorrhops ritchieana* is a gregarious species that grows in water-scarce areas in association with subtropical scrubby types of vegetation where they are completely exposed to sunlight.

7.3 *NANNORRHOPS RITCHIEANA* ASSOCIATIONS OR COMMUNITY ECOLOGY

For a proper understanding of the species' ecology, it is mandatory to study who are the neighbors and what environmental factors control its populations. How linkages among species and their environment developed and how they in combination affect the diversity, distribution and abundance within an association or community (Johnson and Stinchcombe, 2007). Many studies in every biome of the globe have documented that plant species can have vital positive impacts on their associated species (Lortie *et al.*, 2004). They facilitate each other in water absorption or by providing nutrients, organic matter, and many other essential substances (Brooker *et al.*, 2008), and hence lead to diverse associations and communities. On the other hand, some plant species have negative impacts on the neighboring species (Choler *et al.*, 2001). They influence each other by shade effect, competition for nutrients and allelopathy (Qin *et al*., 2018). In this context, we tried in Chapter 05, to identify who lives with *Nannorrhops ritchieana* and what environmental factors control its population within different climatic zones of Khyber Pakhtunkhwa. We studied a total of 251 associated plant species in 63 populations documented in 508 plots. Sampling adequacy was checked by constructing a species-area curve which shows a clear relationship between species and plots. All plots were then divided into four major (clusters) associations by creating a CCA and generalized linear model (Figures 5.4 and 5.5) under the influence of environmental data. Each association was then graphically visualized through a cluster dendrogram. We then identified three indicators, one tree, a shrub and an herb for each association using indicator species analysis. Indicators species were the clear representatives of different climatic zones where *Nannorrhops ritchieana* is distributed. Moreover, we showed the concentration level of different environmental factors across the four climatic zones (Figure 5.13). In addition, we created a CCA plot to understand the distribution of all associated species under the influence of different environmental factors (Figure 5.3.14). We examined the homology in associated species among the four zones by creating Venn diagrams (Figure 5.3.15). All analyses in Chapter 05 prove that *Nannorrhops ritchieana* is a keystone and gregarious species that support its associated flora by providing shelter from herbivores in its dense clumps in Pashto called “Tal”. Being an important shelter provider from herbivores, the species face many problems among them seed dormancy and slow germination like other palm species is the most limiting one.

7.4 SEED DORMANCY AND GERMINATION ECOLOGY

Seed dormancy mostly arises in plants with very small and immature embryos, hard seed coats and unsuitable environmental conditions (Abubakar and Attanda, 2022). The phenomenon of small and immature embryos and hard seed coats is very common in the palm family (Baskin and Baskin, 2014; Jaganathan, 2021). It has been assessed that palm species have a germination rate of less than 20% (Meerow and Alan, 2004). On the other hand, more than 25% of palm species require over 100 days to germinate (Tomlinson, 1990). They are idiosyncratic in the process of germination, seed structure and seedling morphology (Medeiros *et al*., 2015; Tomlinson, 2006). Generally, in palm species low germination levels are common and various types of dormancy are reported (Baskin and

Baskin, 2004). In Chapter 07, we assessed the impact of different techniques used to overcome seed dormancy and enhance seed germination.

We tested the impact of H2SO4, HNO3, Thiourea, Hot water, GA3 and IAA in different concentrations and immersion times.

We found that scarification with H2SO4, HNO3 and Thiourea in low concentrations best-promoted seed germination but gradually a decrease was observed with an increase in acid concentration. The decrease might be due to the increase of acids and thiourea concentration that damages the embryo and triggers seed germination for long time immersion. On the other hand, an increase in GA3 concentration and immersion time leads to a significant increase in seed germination while IAA initiates seed germination irrespective of immersion time. These results reveal that the application of GA3 and IAA provides strength to the embryo in germination. Hot water treatment is the best non-laborious and inexpensive treatment causing a significant increase in seed germination. An increase in time from 5–15 days and 35–45^{o}C temperature caused a considerable increase in seed germination. In addition, we observed that in April, May, June, and July a maximum number of seeds germinated. These months correspond to the summer in the capital of Pakistan where the experiments were carried out at temperature ranges from 35–45^{o}C. Keeping in view the results of all experimentations we elucidate that the hard seed coat is a serious problem to germination. The hot temperature in the summer months is required (Lackner, 2003) which might cause cracks in the seed coat, through which water easily penetrates to the inside and cause germination. On the other hand, high soil humidity is also necessary for seed germination. Now, it is mandatory to convey this information based on practical knowledge, observations and experimentations in a simple and meaningful way.

7.5 FROM SCIENCE TO PRACTICE

It is mandatory to take scientific knowledge into practice in the form of industry, agriculture, or in the management, and development of rules and regulations. Taking science into practice and implementation requires serious involvement of educational and other institutions, nongovernment organizations (NGOs), managers and stakeholders. The government of Pakistan, in 1953 passed an act for the conservation of *Nannorrhops ritchieana*in the Kohat division.

This thesis is a story of more than seven years of my personnel, my team, led by Dr. Shujaul Mulk Khan of the Department of Plant Sciences, Quaid-i-Azam University, Islamabad and currently the struggles of Prof. Henrik Balslev and Anders Sanchez Barfod in the Section for Ecoinformatics and Biodiversity, Department of Biology, Aarhus University, Denmark. In this long time of more than seven years, we researched different aspects of *Nannorrhops ritchieana* including ethnobiology, socioeconomics, ecology (population and community ecology) and seed dormancy. These efforts have already resulted in various publications, and few are in the process of publication. The large extent of information gathered so far through questionnaire surveys, field works and experimentations can play a crucial role in the development of ways for leaves harvesting, cottage industry and handicrafts marketing in a sustainable manner. Moreover, it will help in the understanding of the palm's population status and its associations with other plants and most importantly fostering its restoration through seed dormancy mitigation. *Nannorrhops ritchieana* is the backbone of the livelihood and economic development in some remote areas of Pakistan and neighboring countries which need to develop proper nurseries to improve forest cover and get more benefits using this thesis and our publications as background information.

7.6 CONTRIBUTION TO UN'S SUSTAINABLE DEVELOPMENT GOALS (SDG)

This thesis contributes to all of the United Nation's sustainable development goals (SDGs) in general and a few in particular. No poverty: In Chapter 1, we focused on the traditional knowledge regarding different handicrafts processed from *Nannorrhops ritchieana* which is an economic source of the remote and marginalized communities in Pakistan and neighboring countries that play a crucial role in the battles of poverty and economic crisis through provisioning ecosystem services. With the income local people get from its handicrafts, they fulfill the need for their food which covers the second goal "Zero Hunger". The development of cottage industries will contribute to the goal of "Industry, Innovation and Infrastructure" by generating job opportunities. If we improve the culture of biodegradable handicrafts, goods and utensils that are prepared from *Nannorrhops ritchieana* as an alternative to plastic-based items (for detail see Abdullah *et al*., 2021) it will be a significant contribution to the goal "Sustainable Cities and Communities".

Climate change: for sustainability in nature climate change mitigation is necessary. The information we provide on the population and community ecology of the species can help farmers and forest officers in the identification of suitable areas for *Nannorrhops ritchieana* cultivation. For cultivation, seedlings can be developed in nurseries by using our findings from a few years of experimentation on seed dormancy and germination. In the current scenario of climate change and globalization, *Nannorrhops ritchieana* afforestation will be an important step to sustainability through carbon sequestration. All SDGs are interlinked and therefore we need to focus on their development to bring sustainability to our use of nature.

7.7 Limitations of the Study

I tried my best with the excellent support of my supervisor and different people from the forest department of Khyber Pakhtunkhwa, to complete this project in a better way with excellent results. A key limitation of this study was the geopolitical instabilities in the regions where *Nannorrhops ritchieana* grows. It is mostly distributed in the tribal belt of Pakistan along the Durand line. During the last two decades, this region has faced the problem of insurgencies and a few times I was besieged by armed forces in Hangu, Kurram, Orakzai and Mohmand. They properly searched all my belongings (soil samples, seeds, leaves, food and other field accessories). In those days drone attacks were very common and the use of GPS was considered a crime because it is mostly used to provide the location for targeting a region. In such circumstances, we explored 63 populations including 508 plots across the province of Khyber Pakhtunkhwa. But I missed the districts of South and North Waziristan where *Nannorrhops ritchieana* populations exist. I tried and I did visit Mir Ali but due to insurgencies, the armed forces did not allow me to explore the area because some of the regions were the hideouts of the invaders. Another key limitation of this research was that due to financial issues (the total financial support was from my family and friends), we did not install cameras for trapping the porcupine and black bear movements and uprooting activities despite it being essential to understand.

Box, 7.1 The Kohat Mazri Control Act 1953,

In 1953 government of Pakistan passed this legislative act for the consolidation and amendment of law for the conservation of Mazri Palm (Nannorrhops ritchieana). It focuses on the three Ps i.e., protection, preservation and propagation of Nannorrhops ritchieana in the Kohat division. The Act starts with a preamble stating why the amendment and consolidation of this act were needed in the region. The rest of the act comprised 19 sections that cover different aspects of the conservation and management of this palm.

Section 1: This section is comprised of the title "The Kohat Mazri Control Act 1953". It specifies the extent of the act which is Kohat division. The section also mentions that the

Provincial Government has the power to extend or exempt specific areas in the North West Frontier Province (Khyber Pakhtunkhwa) from the provision of the Act.
Section 2: This section defines different terms used in the Act i.e., Mazri, Mazri produce, Cattle, Mazri Offence, Forest Officer, Village forest officer, Conservator, Settlement, Reserved forests, and Wasteland.
Section 3: This section reveals that according to this Act, Nannorrhops ritchieana shall be a protected plant species wherever it occurs in the Kohat division. It also forbids the harvesting of its leaves, stems, shoots (palm heart) and roots except those allowed by the roles mentioned in the Act.
Section 4: This section encourages the government to issue orders and instructions for the conservation of this palm and its produce in different areas with a proper focus on the protection, preservation and propagation. This section also empowers the government to specify the period for harvesting without that months Nannorrhops ritchieana cannot be harvested or transported. In addition, this section allows the government to reveal the maximum amount of Nannorrhops ritchieana produce that a person can own.
Section 5: This section describes the management of Nannorrhops ritchieana growing territories, comprising wastelands that have been denuded for this palm will assign to the Forest department. It allows the Conservator to issue orders forbidding the interruption in wastelands for cultivation or any other purpose to protect or regenerate Nannorrhop ritchieana. It also empowers the Conservator to confiscate and seize any property in the case of violations of such orders.
Section 5: This section provides the power to the conservator of forests to control and regulate the export and sale of various handicrafts, goods and utensils processed from Nannorrhop ritchieana within or outside of the Kohat division. According to this section the Conservator has to appoint markets for the sale of Nannorrhops ritchieana produce and restrict that only to those markets with property duties of levies/police on the export.
Section 7: This section reveals that the income generated from the leaves and produce of Nannorrhop ritchieana collected from the land owned by the government shall be credited to the government as Forest Revenue.
Section 8: This section brief that the Nannorrhop ritchieana income generated from wastelands, after deducting departmental tax specified by the government, shall be paid to the right person in proportion to their part through the Revenue Department.
Section: in this section the Conservators has empowered with the approval of the government, to notify the prohibition of the harvesting of Nannorrhop ritchieana and regulate its harvesting and transportation for the domestic requirements of the holders.
Section 10:
This section provides Revenue, Police, Levi, Forest, or Village Officers the permission to search and seize any Nannorrhop ritchieana produce in violation of the Act or any rule or order made under it. It also fixes that searches should be carried out according to the terms and conditions of the Criminal Procedure Code.
Section 11: This section demonstrates that anyone who violates the instruction, orders, or rules made in the light of the Act can be convicted before a Magistrate. The person might be punished by Magistrate for up to six months imprisonment or fined up to five thousand PKR, or both. It also allows the Magistrate to seize the Nannorrhop ritchieana produce involved in the offense.
Section 12: This section transfers the power of arrest to Forest, Revenue and Police officers for offenses mentioned in the Act, and anyone arrested according to this section should be presented before the magistrate.

Section 13: This section authorizes the officer arresting a person under Section 12 to release the person on bond, with or without sureties, pending trial. If the person fails to provide the bond, then might be sent to prison.
Section 14: This section grants the incharge of a police station or any other officer authorized by the government to compound violations committed under the roles of the Act upon the payment of a total not exceeding 50 rupees.
Section 15: This section reveals the imposition of the punishment, on any person who illegally retains possession of any property sanctioned under the Act without legal authorization. The person might be punished by Magistrate for up to six months imprisonment or fined up to five thousand PKR, or both as mentioned in section 11.
Section 16: This section provides the power to the Provincial Government to devise rules. The rules may order penalties for offenses, and regulate the harvesting method and period, possession, sale and transportation of Nannorrhops ritchieana. It may prescribe rules for the recovery of any expenditures used in the protection, preservation and propagation of Nannorrhops ritchieana.
Section 17: This section demands the rules prescribed under different sections of the Act to be published in the official gazette of the Forest Department.
Section 18: This section abrogates the Kohat Mazri Control Act, 1949, and all other legislation or part of any legislation contradictory with the rules of the Act 1953. It also protects any action taken under the abrogated Act, which shall be judged to have to have been taken under the subsequent roles of this Act.
Section 19: This section is comprised of the Acts and Ordinances that are abrogated by the Kohat Mazri Control Act, 1953.
Note this is the summary of "The Kohat Mazri Control Act 1953" that could be traced via this link.
https://kp.gov.pk/page/the_kohat_mazri_control_act_1953/page_type/203.215.166.82/203.215.166.82/#:~:text=For%20the%20purposes%20of%20this,or%20stem%20shall%20be%20prohibited.

CONCLUSIONS

This thesis provides a detailed and comprehensive presentation of knowledge and information based on extensive fieldwork, exploration, and experimentation on the different aspects of the biology of *Nannorrhops ritchieana.* It focuses on the multitude of ecosystem services, socioeconomic importance, population ecology, diverse associations, and seed dormancy mitigation. The ecosystem services of *Nannorrhops ritchieana* vary across different cultural regions within the province of Khyber Pakhtunkhwa, populated by different ethnic groups. In some areas, intense over-harvesting has led to extinction. The number of seedlings is lower than that of juvenile and young-age plants, posing a challenge to its sustainability. The extinction of *Nannorrhops ritchieana* population could result in the extinction of associated plants and animals. Over the past six years, it has been observed and documented that the Indian porcupine, which consumes its roots as its favorite food, is also decreasing as the population of *Nannorrhops ritchieana* declines. We provide a synopsis of the importance of seed dormancy alleviation for the future conservation of this palm. This can be accomplished by treating seeds with hot water stratification for 5–15 days and applying GA3 and IAA in various concentrations and sowing months from May to August. Afforestation of *Nannorrhops ritchieana* within its geographic range is highly recommended, with proper implementation of the future implications and roles mentioned in this thesis and The Kohat Mazri Control Act 1953 in Khyber Pakhtunkhwa and other regions of Pakistan and adjacent countries.

Implications for Protection and Conservation

In the coming years, the sustainable use of *Nannorrhops ritchieana* will be critical for biocultural conservation due to the incessant increase in the indigenous populations of Pakistan and particularly the communities living along the Durand line in Khyber Pakhtunkhwa and Baluchistan. The increasing encroachment in the species' habitat by oil and gas (Kurram, Kohat, Karak, Hangu), mining of coal (Orakzai, Dara Adam Khel), marble stone (Khyber, Mohamnd, Bajaur), soapstone and manganese (Bajaur), nephrite and chromite (Mohamnd) and unplanned plantations are the serious threats to its conservation. The unplanned plantations of different species of *Eucalyptus*, and *Prosopis juliflora* are chronic problems not only for *Nannorrhops ritchieana* but also for its associated species. Moreover, road construction (CPEC), forest fire, expansion in agricultural land, and the huge flood regimes in the current decade are major contributing factors that open the door for its extinction. Our research shows that thousands of households rely on the provisioning services of *Nannorrhops ritchieana* and calls for conservation and sustainable utilization to keep the flow of plant-based utensils. In this dissertation, I suggest the extension of the rules and regulations devised in the Kohat Mazri Control Act 1953 (see in detail in Box, 7.1) to all regions of the country hosting *Nannorrhops ritchieana* populations. In addition, a few future recommendations based on my long-time exploration and experimentation are;

(1) Species germination in the optimum germination conditions (May-August).

(2) Establishment of plant nurseries for future plantation and propagation.

(3) Plantation along the motorways, and highways as well as in public offices as an ornamental palm.

(4) *Nannorrhops ritchieana* gardens development is required in coordination with different botanical gardens in the country.

(5) Avoid invasive species plantation in the species' habitat.

(6) Coordination with the media, filmmakers and the press to carry out a publicity campaign on the uniqueness and cultural values of the species.

(7) Develop cottage industries that use the species sustainably and foster its cultural values.

(8) More development and ornamentation are needed in handicrafts to meet the demand of modern societies and boost their economic values.

Recommendations for Future Studies

(i) Phylogenetic investigation of the species is required through proper collections from all countries where it is distributed to solve the mystery whether it is a single species or many species.

(ii) Species distribution modeling is required to predict its future distribution.

(iii) Species germination is required in control environments using growth chambers to properly understand the impact of temperature regimes on seed germination.

(iv) A study on mycorrhizal associations is also recommended to know why the species is restricted distribution to some regions.

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APPENDICES

Appendix 4.1 Summary of Population ecology data of *Nannorrhops ritchieana*

EWMZ					
Variable	Mean	SEMean	StDev	Minimum	Maximum
IVI	64.23	5.35	22.7	27	100
Cover	29.78	4.5	19.08	4	72
Density	4.222	0.862	3.655	1	12
Seedling	2	*	*	2	2
Juvenile	3	0.447	1	2	4
Young	1.533	0.236	0.915	1	4
Midlle age	2	0.314	1.177	1	5
Old age plants	1	0	0	1	1
NDMZ					
Variable	Mean	SEMean	StDev	Minimum	Maximum
IVI	74.08	1.91	24.3	22.22	100
Cover	42.44	1.88	23.94	2	95
Density	3.204	0.238	3.024	1	18
Seedling	3.5	1.5	3	2	8
Juvenile	3.688	0.35	3.132	1	15
Young	2.072	0.184	1.527	1	8
Midlle age	1.2917	0.0663	0.4593	1	2
Old age plants	1.571	0.202	0.535	1	2
WDMZ					
Variable	Mean	SEMean	StDev	Minimum	Maximum
IVI	78.05	1.09	16.2	25	100
Cover	46.96	1.44	21.41	6	98
Density	5.414	0.228	3.401	1	24
Seedling	4.333	0.788	3.61	1	17
Juvenile	4.006	0.254	3.271	1	17
Young	2.092	0.108	1.281	1	8
Midlle age	1.631	0.097	0.8887	1	4
Old age plants	1.3	0.213	0.675	1	3
SPMZ					
Variable	Mean	SEMean	StDev	Minimum	Maximum
IVI	80.28	1.73	17.79	33.33	100
Cover	43.36	2.16	22.26	5	88
Density	25.6	21.2	219	1	2269
Seedling	56.5	53.5	75.7	3	110
Juvenile	21.2	17.4	146.9	1	1241
Young	11.1	8.72	73.98	1	630
Midlle age	12.1	10.7	52.6	1	259
Old age plants	10.33	9.33	16.17	1	29

Appendix 4.2 Summary of fruit ecology data of *Nannorrhops ritchieana*

Young age plants					
	Mean	SE Mean	StDev	Minimum	Maximum
Plant height	82.44	3.68	15.18	45.54	97.71
Inflorescence length	41.581	0.394	1.626	38.608	44.45
Fruit number	377.65	9.23	38.07	317	448
Fruit size	15.324	0.105	0.431	14.6	16.1
Seed Size	12.329	0.275	1.135	9.8	13.8
Middle age plants					
Mean		SE Mean	StDev	Minimum	Maximum
Plant height	144.98	5.71	27.38	107.61	193.51
Inflorescence length	571.8	39.9	191.5	267	981
Fruit number	14.265	0.221	1.059	12.2	15.8
Fruit size	16.965	0.317	1.52	14.3	18.7
Seed Size	63.2	10.4	50	38.4	206
Old age plants					
Mean		SE Mean	StDev	Minimum	Maximum
Plant height	258.5	12.8	42.5	204.7	323.9
Inflorescence length	206.18	8.36	27.71	141	241
Fruit number	11.262	0.199	0.66	10.2	11.9
Fruit size	13.316	0.193	0.639	12.4	14.3
Seed Size	35.68	0.659	2.185	31.496	38.1

Appendix 5.1 Descriptive statistics of all environmental variables of 01 Association EWMZ

Variable	**Variance**	**Coef Var**	**Minimum**	**Maximum**	**Median**	**Mean**	**StDev**
Latitude	0.006	0.22	34.2	34.34	34.2	34.26	0.076
Longitude	0.006	0.11	73.07	73.22	73.07	73.13	0.077
Altitude	5159	6.33	1026	1217	1159	1135	71.8
Specific humidity	0.18	5.64	7.069	7.899	7.899	7.53	0.425
RH2M	1.105	2.15	47.88	49.94	47.88	48.79	1.051
Dew	1.114	19.29	4.324	6.388	6.388	5.471	1.055
Surface Soil Wetness	6E-05	1.4	0.539	0.554	0.554	0.547	0.008

Temperature Max	4.504	5.31	37.64	41.79	41.79	39.94	2.122
Temperature Min	0.184	7.32	5.395	6.234	6.234	5.861	0.429
Profile Soil Moisture	0.01	15.15	0.558	0.756	0.756	0.668	0.101
Root zone soil wetness	6E-04	4.06	0.567	0.614	0.614	0.593	0.024
Wind Speed_Max	0.205	6.95	6.022	6.908	6.908	6.514	0.453
Wind Speed_Min	5E-06	7.52	0.027	0.031	0.027	0.029	0.002
Precipitation	0.027	6.78	2.222	2.54	2.54	2.398	0.163
Iron	4E-04	59.15	0.019	0.102	0.023	0.034	0.02
Sodium	0.03	77.45	0.041	0.515	0.176	0.222	0.172
Calcium	0.002	22.34	0.159	0.329	0.194	0.215	0.048
Potassium	3E-04	143.2	0.002	0.081	0.009	0.012	0.018
pH	0.348	7.31	6.9	8.94	8.02	8.068	0.59
Electrical Conductivity	8085	104.9	31.8	346	50.4	85.7	89.9
Total dissolved solids	32384	185.5	17	620	31	97	180
Magnesium	335.2	80.28	7.67	63.12	13.99	22.81	18.31
Sand	89.78	38.5	8	44	25.5	24.61	9.48
Silt	290.2	42.41	12	68	43	40.17	17.03
Clay	354.1	53.42	10	80	34	35.22	18.82

Appendix 5.2 Descriptive statistics of all environmental variables of 02 Association NDMZ

Variable	Variance	CoefVar	Minimum	Median	Maximum	Mean	StDev
Latitude	0.0126	0.32	34.273	34.59	34.882	34.602	0.112
Longitude	0.0122	0.15	71.33	71.611	71.853	71.626	0.111
Altitude	37816	19.65	613	935	1541	989.7	194.5
Specific humidity	2.152	20.12	2.76	7.214	12.086	7.289	1.467
RH2M	66.224	18.63	40.981	41.422	74.977	43.67	8.138
Dew	1.901	28.42	0.455	5.428	5.428	4.85	1.379
Surface Soil Wetness	93.587	358.7	0.411	0.411	45.002	2.697	9.674
Temperature Max	100.735	24.2	1.065	45.002	45.002	41.476	10.037
Temperature Min	6.856	121.04	1.065	1.065	10.386	2.163	2.618
Profile Soil Moisture	58101.6	387.85	0.5	0.5	999	62.1	241
Root zone soil wetness	58101.5	387.85	0.4	0.5	999	62.1	241
Wind Speed_Max	3.983	31.62	5.515	5.716	13.796	6.313	1.996
Wind Speed_Min	0.00005	26.12	0.01975	0.02575	0.05275	0.026982	0.007049
Precipitation	0.0031	3.69	1.3242	1.5283	1.5643	1.5072	0.0557
Iron	0.00033	55.03	0.00764	0.028	0.0858	0.03302	0.01817
Sodium	0.00092	46.33	0.001	0.06822	0.12269	0.0655	0.03034
Calcium	0.00224	23.36	0.04322	0.19964	0.29194	0.20267	0.04735
Potassium	0.00238	119.67	0.00027	0.01456	0.23526	0.04075	0.04876
pH	0.5538	9.53	6.4	8.09	9.01	7.812	0.7442
Electrical Conductivity	5219.33	85.95	8.27	61.7	511	84.06	72.24

Total dissolved solids	5262.2	97.29	11	54	491	74.56	72.54
Magnesium	278.12	58.92	2.91	28.86	63.43	28.3	16.68
Sand	138.961	49.29	4	22	68	23.914	11.788
Silt	311.53	33.57	9	51.5	93	52.57	17.65
Clay	228.73	63.85	2	21	80	23.69	15.12

Appendix 5.3 Descriptive statistics of all environmental variables of 03 Association WDMZ

Variable	Variance	CoefVar	Minimum	Maximum	Median	Mean	StDev
Lati	0.06	0.75	33.27	34.61	33.50	33.54	0.25
Long	0.12	0.48	70.21	71.61	70.95	70.85	0.34
Alti	73298.40	28.94	0.00	2163.70	895.70	935.60	270.70
SH2M	3.67	28.99	2.73	12.24	6.23	6.61	1.92
RH2M	172.23	28.43	40.33	94.95	41.05	46.17	13.12
Dew	5.26	67.77	0.68	10.75	2.51	3.38	2.29
Dew	5.26	67.77	0.68	10.75	2.51	3.38	2.29
SSW	0.02	32.73	0.40	1.00	0.40	0.47	0.15
T2Max	26.72	12.74	21.94	44.99	41.45	40.56	5.17
T2Min	8.37	91.60	0.47	11.34	2.99	3.16	2.89
PSM	34787.10	510.69	0.50	999.00	0.50	36.50	186.50
RZSW	34786.80	510.62	0.50	999.00	0.50	36.50	186.50
WS2Max	2.66	19.04	4.32	13.30	8.60	8.56	1.63
WS2Min	0.00	59.27	0.02	0.10	0.02	0.03	0.02
Precipitation	0.85	57.07	1.13	4.71	1.30	1.62	0.92
Fe	0.00	43.88	0.02	0.10	0.04	0.04	0.02
Na	0.01	92.86	0.01	0.50	0.08	0.11	0.10
Ca	0.00	24.36	0.04	0.29	0.21	0.20	0.05
K	0.01	124.22	0.00	0.27	0.01	0.06	0.08
pH	0.24	5.99	6.40	9.01	8.40	8.26	0.49
EC	13928.32	114.04	0.00	1005.00	72.70	103.49	118.02

TDS	12984.47	122.32	15.00	945.00	58.50	93.15	113.95
Mg	230.14	50.08	4.18	64.43	28.95	30.29	15.17
Sand	132.05	46.83	4.00	71.00	23.00	24.54	11.49
Silt	336.78	35.85	9.00	93.00	49.00	51.18	18.35
Clay	252.19	65.24	0.00	80.00	22.00	24.34	15.88

Appendix 5.4 Descriptive statistics of all environmental variables of 04 Association SPMZ

Variable	Variance	CoefVar	Minimum	Maximum	Median	Mean	StDev
Lati	0.00224	0.15	32.182	32.377	32.292	32.28	0.0473
Long	0.146	0.54	70.074	71.096	70.804	70.581	0.382
Alti	82335.9	52.83	245	1340	590	543.2	286.9
SH2M	0.5295	10.88	5.852	7.7583	6.9285	6.6883	0.7277
RH2M	3.053	4.95	32.694	37.163	36.624	35.282	1.747
Dew	5.39	56.98	1.303	7.224	4.941	4.075	2.322
Dew	5.39	56.98	1.303	7.224	4.941	4.075	2.322
SSW	0.0005	7.06	0.2825	0.3375	0.3315	0.31734	0.02241
T2Max	7.492	5.99	42.033	48.734	46.999	45.697	2.737
T2Min	0.5801	36.81	1.0422	2.8853	2.54	2.0691	0.7617
PSM	0.0001	2.12	0.46775	0.49775	0.4875	0.48233	0.01021
RZSW	0.00012	2.29	0.466	0.4965	0.48775	0.48082	0.01102
WS2Max	0.173	4.76	8.15	9.2505	8.7675	8.7419	0.416
WS2Min	1E-06	3.02	0.0245	0.02675	0.0265	0.02594	0.00078
Precipitation	0.00933	10.44	0.76225	1.06825	0.9375	0.92548	0.09661
Fe	0.00176	50.98	0.01708	0.12672	0.106	0.08229	0.04195

Na	0.00167	110.62	0.00048	0.25314	0.02267	0.03698	0.04091
Ca	0.0115	69.67	0.0213	0.3286	0.1626	0.1541	0.1074
K	0.00148	86.19	0.00272	0.12469	0.04562	0.0446	0.03844
pH	0.529	9.21	6.665	9.43	7.84	7.8948	0.7273
EC	11348.3	108.03	21.5	1005	78	98.6	106.5
TDS	13830	140.54	21	945	57	83.7	117.6
Mg	270.94	100.44	3.43	63.12	7.15	16.39	16.46
Sand	135.25	43.37	8	71	25	26.81	11.63
Silt	302.43	32.79	9	90	52	53.04	17.39
Clay	205.47	71.14	0	76	18	20.15	14.33

Appendix 6.1 Germination indices of H_2SO_4 experiment

rep	H2SO4	Time	seeds	grs	grp	mgt	mgr	gsp	unc	Syn	vgt	sdg	cvg
1	0	0	10	5	50	4.4	0.227	22.727	2.322	0	8.3	2.881	65.477
2	0	0	10	6	60	5.667	0.176	17.647	2.585	0	9.067	3.011	53.137
3	0	0	10	4	40	5	0.2	20	2	0	13.333	3.651	73.03
4	0	0	10	6	60	6	0.167	16.667	2.585	0	9.2	3.033	50.553
Avg					52.5	5.2668	0.1925	19.2603	2.373	0	9.975	3.144	60.54925
1	5	6	10	7	70	5.286	0.189	18.919	2.807	0	12.238	3.498	66.184
2	5	6	10	8	80	5.875	0.17	17.021	3	0	9.839	3.137	53.392
3	5	6	10	9	90	5.778	0.173	17.308	3.17	0	9.444	3.073	53.19
4	5	6	10	8	80	4.5	0.222	22.222	3	0	6	2.449	54.433
Avg					80	5.3598	0.1885	18.8675	2.9943	0	9.38025	3.0393	56.79975
1	5	12	10	7	70	5.429	0.184	18.421	2.807	0	8.952	2.992	55.117
2	5	12	10	8	80	6.25	0.16	16	3	0	7.929	2.816	45.052
3	5	12	10	7	70	6.286	0.159	15.909	2.807	0	10.571	3.251	51.726
4	5	12	10	8	80	5.125	0.195	19.512	3	0	9.839	3.137	61.205
Avg					75	5.7725	0.1745	17.4605	2.9035	0	9.32275	3.049	53.275
1	5	18	10	7	70	5.143	0.194	19.444	2.807	0	11.143	3.338	64.907
2	5	18	10	7	70	5.429	0.184	18.421	2.807	0	9.619	3.101	57.132
3	5	18	10	6	60	5.167	0.194	19.355	2.585	0	12.167	3.488	67.511
4	5	18	10	8	80	4.5	0.222	22.222	3	0	6	2.449	54.433
Avg					70	5.0598	0.1985	19.8605	2.7998	0	9.73225	3.094	60.99575
1	5	24	10	7	70	5.286	0.189	18.919	2.807	0	12.238	3.498	66.184
2	5	24	10	6	60	5	0.2	20	2.585	0	10	3.162	63.246
3	5	24	10	7	70	5.286	0.189	18.919	2.807	0	10.571	3.251	61.512
4	5	24	10	5	50	3.6	0.278	27.778	2.322	0	5.8	2.408	66.898
Avg					62.5	4.793	0.214	21.404	2.6303	0	9.65225	3.0798	64.46

1	10	6	10	7	70	5.857	0.171	17.073	2.807	0	9.143	3.024	51.624
2	10	6	10	6	60	5.167	0.194	19.355	2.585	0	12.167	3.488	67.511
3	10	6	10	6	60	4.5	0.222	22.222	2.585	0	7.5	2.739	60.858
4	10	6	10	6	60	4.833	0.207	20.69	2.585	0	14.167	3.764	77.873
Avg					62.5	5.0893	0.1985	19.835	2.6405	0	10.7443	3.2538	64.4665
1	10	12	10	5	50	5.4	0.185	18.519	2.322	0	16.3	4.037	74.765
2	10	12	10	5	50	5	0.2	20	2.322	0	10	3.162	63.246
3	10	12	10	6	60	5.833	0.171	17.143	2.585	0	10.167	3.189	54.66
4	10	12	10	6	60	4.667	0.214	21.429	2.585	0	6.667	2.582	55.328
Avg					55	5.225	0.1925	19.2728	2.4535	0	10.7835	3.2425	61.99975
1	10	18	10	5	50	5	0.2	20	2.322	0	12.5	3.536	70.711
2	10	18	10	6	60	5.167	0.194	19.355	2.585	0	10.967	3.312	64.095
3	10	18	10	5	50	4.8	0.208	20.833	2.322	0	11.2	3.347	69.722
4	10	18	10	6	60	4.333	0.231	23.077	2.585	0	7.867	2.805	64.725
Avg					55	4.825	0.2083	20.8163	2.4535	0	10.6335	3.25	67.31325
1	10	24	10	4	40	5	0.2	20	2	0	13.333	3.651	73.03
2	10	24	10	5	50	5.6	0.179	17.857	2.322	0	12.3	3.507	62.627
3	10	24	10	5	50	5.4	0.185	18.519	2.322	0	14.8	3.847	71.242
4	10	24	10	4	40	4.25	0.235	23.529	2	0	8.917	2.986	70.261
Avg					45	5.0625	0.1998	19.9763	2.161	0	12.3375	3.4978	69.29
1	15	6	10	3	30	4.667	0.214	21.429	1.585	0	4.333	2.082	44.607
2	15	6	10	3	30	5	0.2	20	1.585	0	19	4.359	87.178
3	15	6	10	4	40	7.75	0.129	12.903	2	0	4.917	2.217	28.611
4	15	6	10	3	30	3	0.333	33.333	1.585	0	4	2	66.667
Avg					32.5	5.1043	0.219	21.9163	1.6888	0	8.0625	2.6645	56.76575
1	15	12	10	4	40	5.25	0.19	19.048	2	0	16.25	4.031	76.783
2	15	12	10	3	30	4.667	0.214	21.429	1.585	0	12.333	3.512	75.255

3	15	12	10	4	40	4.75	0.211	21.053	2	0	8.917	2.986	62.865
4	15	12	10	3	30	6	0.167	16.667	1.585	0	4	2	33.333
Avg					35	5.1668	0.1955	19.5493	1.7925	0	10.375	3.1323	62.059
1	15	18	10	3	30	3.333	0.3	30	1.585	0	10.333	3.215	96.437
2	15	18	10	5	50	4	0.25	25	2.322	0	2.5	1.581	39.528
3	15	18	10	3	30	7	0.143	14.286	1.585	0	4	2	28.571
4	15	18	10	2	20	8	0.125	12.5	1	0	2	1.414	17.678
Avg					32.5	5.5833	0.2045	20.4465	1.623	0	4.70825	2.0525	45.5535
1	15	24	10	3	30	4.333	0.231	23.077	1.585	0	24.333	4.933	113.836
2	15	24	10	1	10	1	1	100	0				
3	15	24	10	2	20	2.5	0.4	40	1	0	4.5	2.121	84.853
4	15	24	10	2	20	6.5	0.154	15.385	1	0	4.5	2.121	32.636
Avg					20	3.5833	0.4463	44.6155	0.8963	0	11.111	3.0583	77.10833

Appendix 6. 2 Germination indices of HNO3 experiment

rep	HNO3	Time	seeds	grs	grp	mgt	mgr	gsp	unc	syn	vgt	sdg	cvg
1	0	0	10	5	50	4.4	0.227	22.727	2.322	0	8.3	2.881	65.477
2	0	0	10	6	60	5.667	0.176	17.647	2.585	0	9.067	3.011	53.137
3	0	0	10	4	40	5	0.2	20	2	0	13.333	3.651	73.03
4	0	0	10	6	60	6	0.167	16.667	2.585	0	9.2	3.033	50.553
					52.5	5.2668	0.1925	19.2603	2.373	0	9.975	3.144	60.54925
1	5	6	10	7	70	5.286	0.189	18.919	2.807	0	12.238	3.498	66.184
2	5	6	10	7	70	6.143	0.163	16.279	2.807	0	10.81	3.288	53.522
3	5	6	10	7	70	5.143	0.194	19.444	2.807	0	10.143	3.185	61.926
4	5	6	10	8	80	4.5	0.222	22.222	3	0	6	2.449	54.433
					72.5	5.268	0.192	19.216	2.8553	0	9.79775	3.105	59.01625
1	5	12	10	7	70	5.429	0.184	18.421	2.807	0	8.952	2.992	55.117
2	5	12	10	7	70	6.143	0.163	16.279	2.807	0	9.143	3.024	49.223
3	5	12	10	7	70	6.286	0.159	15.909	2.807	0	10.571	3.251	51.726
4	5	12	10	7	70	4.857	0.206	20.588	2.807	0	10.81	3.288	67.69
					70	5.6788	0.178	17.7993	2.807	0	9.869	3.1388	55.939
1	5	18	10	6	60	5.167	0.194	19.355	2.585	0	13.367	3.656	70.762
2	5	18	10	6	60	5.5	0.182	18.182	2.585	0	11.5	3.391	61.658
3	5	18	10	7	70	5.714	0.175	17.5	2.807	0	12.238	3.498	61.22
4	5	18	10	8	80	4.5	0.222	22.222	3	0	6	2.449	54.433
					67.5								
1	5	24	10	6	60	5	0.2	20	2.585	0	14	3.742	74.833
2	5	24	10	7	70	5.571	0.179	17.949	2.807	0	10.619	3.259	58.489
3	5	24	10	6	60	5	0.2	20	2.585	0	12	3.464	69.282
4	5	24	10	6	60	4.5	0.222	22.222	2.585	0	9.5	3.082	68.493

					62.5								
1	10	6	10	6	60	5.833	0.171	17.143	2.585	0	10.967	3.312	56.77
2	10	6	10	7	70	5.429	0.184	18.421	2.807	0	10.619	3.259	60.028
3	10	6	10	7	70	4.714	0.212	21.212	2.807	0	6.571	2.563	54.377
4	10	6	10	6	60	4.833	0.207	20.69	2.585	0	14.167	3.764	77.873
					65								
1	10	12	10	5	50	5.4	0.185	18.519	2.322	0	16.3	4.037	74.765
2	10	12	10	6	60	5.167	0.194	19.355	2.585	0	8.167	2.858	55.311
3	10	12	10	6	60	5.833	0.171	17.143	2.585	0	10.167	3.189	54.66
4	10	12	10	6	60	4.333	0.231	23.077	2.585	0	4.667	2.16	49.852
					57.5								
1	10	18	10	6	60	5.167	0.194	19.355	2.585	0	10.167	3.189	61.713
2	10	18	10	5	50	5.4	0.185	18.519	2.322	0	13.3	3.647	67.535
3	10	18	10	5	50	4.8	0.208	20.833	2.322	0	11.2	3.347	69.722
4	10	18	10	5	50	3.8	0.263	26.316	2.322	0	7.7	2.775	73.023
					52.5								
1	10	24	10	4	40	5	0.2	20	2	0	13.333	3.651	73.03
2	10	24	10	5	50	5.6	0.179	17.857	2.322	0	12.3	3.507	62.627
3	10	24	10	5	50	5.8	0.172	17.241	2.322	0	12.2	3.493	60.222
4	10	24	10	5	50	5.2	0.192	19.231	2.322	0	11.2	3.347	64.358
					47.5								
1	15	6	10	4	40	4.75	0.211	21.053	2	0	2.917	1.708	35.954
2	15	6	10	5	50	5	0.2	20	2.322	0	10	3.162	63.246
3	15	6	10	5	50	6.8	0.147	14.706	2.322	0	8.2	2.864	42.111
4	15	6	10	4	40	4.25	0.235	23.529	2	0	8.917	2.986	70.261
					45								
1	15	12	10	4	40	5.25	0.19	19.048	2	0	16.25	4.031	76.783

2	15	12	10	3	30	4.667	0.214	21.429	1.585	0	12.333	3.512	75.255
3	15	12	10	4	40	4.75	0.211	21.053	2	0	8.917	2.986	62.865
4	15	12	10	4	40	6.75	0.148	14.815	2	0	4.917	2.217	32.85
					37.5								
1	15	18	10	3	30	3.333	0.3	30	1.585	0	10.333	3.215	96.437
2	15	18	10	4	40	3.75	0.267	26.667	2	0	2.917	1.708	45.542
3	15	18	10	3	30	7	0.143	14.286	1.585	0	4	2	28.571
4	15	18	10	3	30	7.333	0.136	13.636	1.585	0	2.333	1.528	20.83
					32.5								
1	15	24	10	3	30	4.333	0.231	23.077	1.585	0	24.333	4.933	113.836
2	15	24	10	2	20	4.5	0.222	22.222	1	0	24.5	4.95	109.994
3	15	24	10	3	30	3.333	0.3	30	1.585	0	4.333	2.082	62.45
4	15	24	10	3	30	6.333	0.158	15.789	1.585	0	2.333	1.528	24.119
					27.5								

Appendix 6.3 Germination indices of Hot water treatment experiment

rep	Hwt	Time	seeds	grs	grp	mgt	mgr	gsp	unc	syn	vgt	sdg	cvg
1	0	0	10	5	50	5	0.2	20	2.322	0	5	2.236	44.721
2	0	0	10	6	60	5.667	0.176	17.647	2.585	0	9.067	3.011	53.137
3	0	0	10	5	50	4.8	0.208	20.833	2.322	0	10.2	3.194	66.536
4	0	0	10	6	60	6.167	0.162	16.216	2.585	0	8.167	2.858	46.342
					55								
1	35	5	10	8	80	5.625	0.178	17.778	3	0	9.125	3.021	53.702
2	35	5	10	7	70	6.286	0.159	15.909	2.807	0	10.571	3.251	51.726
3	35	5	10	7	70	5.429	0.184	18.421	2.807	0	10.619	3.259	60.028
4	35	5	10	8	80	4.5	0.222	22.222	3	0	6	2.449	54.433

					75								
1	40	5	10	7	70	6.571	0.152	15.217	2.807	0	7.952	2.82	42.913
2	40	5	10	7	70	5.286	0.189	18.919	2.807	0	10.571	3.251	61.512
3	40	5	10	8	80	5.75	0.174	17.391	3	0	10.786	3.284	57.116
4	40	5	10	7	70	5	0.2	20	2.807	0	11.333	3.367	67.33
					72.5								
1	45	5	10	8	80	6	0.167	16.667	3	0	10.286	3.207	53.452
2	45	5	10	6	60	6.5	0.154	15.385	2.585	0	9.5	3.082	47.419
3	45	5	10	7	70	6.143	0.163	16.279	2.807	0	7.81	2.795	45.493
4	45	5	10	8	80	5.625	0.178	17.778	3	0	11.411	3.378	60.053
					72.5								
1	35	10	10	8	80	6.25	0.16	16	3	0	7.929	2.816	45.052
2	35	10	10	8	80	6.25	0.16	16	3	0	7.929	2.816	45.052
3	35	10	10	6	60	6.167	0.162	16.216	2.585	0	6.167	2.483	40.269
4	35	10	10	6	60	4.833	0.207	20.69	2.585	0	12.567	3.545	73.344
					70								
1	40	10	10	8	80	5.125	0.195	19.512	3	0	8.411	2.9	56.588
2	40	10	10	7	70	4.571	0.219	21.875	2.807	0	8.286	2.878	62.967
3	40	10	10	6	60	5.167	0.194	19.355	2.585	0	13.367	3.656	70.762
4	40	10	10	8	80	5.375	0.186	18.605	3	0	9.125	3.021	56.2
					72.5								
1	45	10	10	7	70	4.714	0.212	21.212	2.807	0	8.238	2.87	60.883
2	45	10	10	8	80	6	0.167	16.667	3	0	9.714	3.117	51.946
3	45	10	10	7	70	5.286	0.189	18.919	2.807	0	13.238	3.638	68.835
4	45	10	10	7	70	5.286	0.189	18.919	2.807	0	12.238	3.498	66.184
					72.5								
1	35	15	10	8	80	5.75	0.174	17.391	3	0	10.786	3.284	57.116

2	35	15	10	8	80	5.75	0.174	17.391	3	0	10.786	3.284	57.116
3	35	15	10	9	90	5.889	0.17	16.981	3.17	0	8.611	2.934	49.831
4	35	15	10	9	90	5.222	0.191	19.149	3.17	0	9.444	3.073	58.848
					85								
1	40	15	10	9	90	5.444	0.184	18.367	3.17	0	10.278	3.206	58.884
2	40	15	10	8	80	5.5	0.182	18.182	3	0	11.143	3.338	60.693
3	40	15	10	8	80	5.75	0.174	17.391	3	0	11.357	3.37	58.609
4	40	15	10	9	90	5	0.2	20	3.17	0	7.5	2.739	54.772
					85								
1	45	15	10	8	80	5.375	0.186	18.605	3	0	11.411	3.378	62.846
2	45	15	10	9	90	5.778	0.173	17.308	3.17	0	9.444	3.073	53.19
3	45	15	10	8	80	4.625	0.216	21.622	3	0	7.125	2.669	57.714
4	45	15	10	8	80	5.75	0.174	17.391	3	0	11.357	3.37	58.609
					82.5								

Appendix 6.4 Germination indices of Gibberellic Acid experiment

rep	**GA3**	**Time**	**seeds**	**grs**	**grp**	**mgt**	**mgr**	**gsp**	**unc**	**syn**	**vgt**	**sdg**	**cvg**
1	0	0	10	5	50	4.4	0.227	22.727	2.322	0	8.3	2.881	65.477
2	0	0	10	6	60	5.667	0.176	17.647	2.585	0	9.067	3.011	53.137
3	0	0	10	4	40	5	0.2	20	2	0	13.333	3.651	73.03
4	0	0	10	6	60	6	0.167	16.667	2.585	0	9.2	3.033	50.553
				5.25	52.5	5.2668	0.1925	19.2603	2.373	0	9.975	3.144	60.5493
1	1000	24	10	7	70	5	0.2	20	2.807	0	15	3.873	77.46
2	1000	24	10	6	60	6.333	0.158	15.789	2.585	0	12.667	3.559	56.195
3	1000	24	10	8	80	5.875	0.17	17.021	3	0	10.696	3.271	55.669
4	1000	24	10	7	70	4.143	0.241	24.138	2.807	0	5.81	2.41	58.18

					70								
1	2000	24	10	8	80	5.75	0.174	17.391	3	0	7.929	2.816	48.97
2	2000	24	10	7	70	5.143	0.194	19.444	2.807	0	10.143	3.185	61.926
3	2000	24	10	8	80	5.25	0.19	19.048	3	0	7.929	2.816	53.634
4	2000	24	10	8	80	5.5	0.182	18.182	3	0	11.714	3.423	62.229
					77.5								
1	3000	24	10	7	70	5.571	0.179	17.949	2.807	0	10.286	3.207	57.564
2	3000	24	10	7	70	6.571	0.152	15.217	2.807	0	7.952	2.82	42.913
3	3000	24	10	8	80	6.375	0.157	15.686	3	0	7.125	2.669	41.871
4	3000	24	10	8	80	5.625	0.178	17.778	3	0	11.411	3.378	60.053
					75								
1	1000	48	10	7	70	5.714	0.175	17.5	2.807	0	6.571	2.563	44.861
2	1000	48	10	6	60	6	0.167	16.667	2.585	0	10.4	3.225	53.748
3	1000	48	10	7	70	6.714	0.149	14.894	2.807	0	7.238	2.69	40.069
4	1000	48	10	9	90	5.111	0.196	19.565	3.17	0	8.611	2.934	57.414
					72.5								
1	2000	48	10	7	70	4.714	0.212	21.212	2.807	0	8.238	2.87	60.883
2	2000	48	10	8	80	5	0.2	20	3	0	8.571	2.928	58.554
3	2000	48	10	7	70	5.714	0.175	17.5	2.807	0	13.238	3.638	63.672
4	2000	48	10	7	70	5.143	0.194	19.444	2.807	0	10.143	3.185	61.926
					72.5								
1	3000	48	10	8	80	5.125	0.195	19.512	3	0	8.411	2.9	56.588
2	3000	48	10	8	80	6	0.167	16.667	3	0	9.714	3.117	51.946
3	3000	48	10	8	80	5.375	0.186	18.605	3	0	11.411	3.378	62.846
4	3000	48	10	7	70	5.286	0.189	18.919	2.807	0	12.238	3.498	66.184
					77.5								
1	1000	72	10	9	90	5.222	0.191	19.149	3.17	0	9.444	3.073	58.848
2	1000	72	10	7	70	5.429	0.184	18.421	2.807	0	11.619	3.409	62.791
3	1000	72	10	8	80	5.625	0.178	17.778	3	0	9.125	3.021	53.702

4	1000	72	10	9	90	5.333	0.188	18.75	3.17	0	10	3.162	59.293
					82.5								
1	2000	72	10	7	70	5	0.2	20	2.807	0	9.667	3.109	62.183
2	2000	72	10	10	100	5.5	0.182	18.182	3.322	0	9.167	3.028	55.048
3	2000	72	10	9	90	5.667	0.176	17.647	3.17	0	10	3.162	55.805
4	2000	72	10	7	70	4.429	0.226	22.581	2.807	0	7.952	2.82	63.677
					82.5								
1	3000	72	10	8	80	5.375	0.186	18.605	3	0	11.411	3.378	62.846
2	3000	72	10	10	100	5.5	0.182	18.182	3.322	0	9.167	3.028	55.048
3	3000	72	10	8	80	4.75	0.211	21.053	3	0	7.929	2.816	59.279
4	3000	72	10	9	90	5.556	0.18	18	3.17	0	10.278	3.206	57.706
					87.5								

Appendix 6.5 Germination indices of Indole acetic acid experiment

rep	**IAA**	**Time**	**seeds**	**grs**	**grp**	**mgt**	**mgr**	**gsp**	**unc**	**syn**	**vgt**	**sdg**	**cvg**
1	0	0	10	5	50	4.4	0.227	22.727	2.322	0	8.3	2.881	65.477
2	0	0	10	6	60	5.667	0.176	17.647	2.585	0	9.067	3.011	53.137
3	0	0	10	4	40	5	0.2	20	2	0	13.333	3.651	73.03
4	0	0	10	6	60	6	0.167	16.667	2.585	0	9.2	3.033	50.553
				5.25	52.5	5.2668	0.1925	19.2603	2.373	0	9.975	3.144	60.5493
1	1000	24	10	8	80	5.125	0.195	19.512	3	0	12.982	3.603	70.304
2	1000	24	10	6	60	6.333	0.158	15.789	2.585	0	12.667	3.559	56.195
3	1000	24	10	8	80	5.875	0.17	17.021	3	0	10.696	3.271	55.669
4	1000	24	10	7	70	4.143	0.241	24.138	2.807	0	5.81	2.41	58.18
				7.25	72.5	5.369	0.191	19.115	2.848	0	10.5388	3.2108	60.087
1	2000	24	10	6	60	6.333	0.158	15.789	2.585	0	9.067	3.011	47.544

2	2000	24	10	7	70	5.143	0.194	19.444	2.807	0	10.143	3.185	61.926
3	2000	24	10	7	70	5.143	0.194	19.444	2.807	0	9.143	3.024	58.794
4	2000	24	10	8	80	5.5	0.182	18.182	3	0	11.714	3.423	62.229
				7	70	5.5298	0.182	18.2148	2.7998	0	10.0168	3.1608	57.6233
1	3000	24	10	7	70	5.571	0.179	17.949	2.807	0	10.286	3.207	57.564
2	3000	24	10	7	70	6.571	0.152	15.217	2.807	0	7.952	2.82	42.913
3	3000	24	10	8	80	6.375	0.157	15.686	3	0	7.125	2.669	41.871
4	3000	24	10	8	80	5.625	0.178	17.778	3	0	11.411	3.378	60.053
				7.5	75	6.0355	0.1665	16.6575	2.9035	0	9.1935	3.0185	50.6003
1	1000	48	10	7	70	5.714	0.175	17.5	2.807	0	6.571	2.563	44.861
2	1000	48	10	6	60	6	0.167	16.667	2.585	0	10.4	3.225	53.748
3	1000	48	10	7	70	6.714	0.149	14.894	2.807	0	7.238	2.69	40.069
4	1000	48	10	7	70	5	0.2	20	2.807	0	10.667	3.266	65.32
				6.75	67.5	5.857	0.1728	17.2653	2.7515	0	8.719	2.936	50.9995
1	2000	48	10	7	70	4.714	0.212	21.212	2.807	0	8.238	2.87	60.883
2	2000	48	10	8	80	5	0.2	20	3	0	8.571	2.928	58.554
3	2000	48	10	7	70	5.714	0.175	17.5	2.807	0	13.238	3.638	63.672
4	2000	48	10	7	70	5.143	0.194	19.444	2.807	0	10.143	3.185	61.926
				7.25	72.5	5.1428	0.1953	19.539	2.8553	0	10.0475	3.1553	61.2588
1	3000	48	10	8	80	5.125	0.195	19.512	3	0	8.411	2.9	56.588
2	3000	48	10	8	80	6	0.167	16.667	3	0	9.714	3.117	51.946
3	3000	48	10	8	80	5.375	0.186	18.605	3	0	11.411	3.378	62.846
4	3000	48	10	7	70	5.286	0.189	18.919	2.807	0	12.238	3.498	66.184
				7.75	77.5	5.4465	0.1843	18.4258	2.9518	0	10.4435	3.2233	59.391
1	1000	72	10	7	70	5.429	0.184	18.421	2.807	0	11.619	3.409	62.791
2	1000	72	10	7	70	5.429	0.184	18.421	2.807	0	11.619	3.409	62.791
3	1000	72	10	8	80	5.625	0.178	17.778	3	0	9.125	3.021	53.702

4	1000	72	10	8	80	5	0.2	20	3	0	10.286	3.207	64.143
				7.5	75	5.3708	0.1865	18.655	2.9035	0	10.6623	3.2615	60.8568
1	2000	72	10	7	70	5	0.2	20	2.807	0	9.667	3.109	62.183
2	2000	72	10	8	80	5.5	0.182	18.182	3	0	11.143	3.338	60.693
3	2000	72	10	7	70	5.571	0.179	17.949	2.807	0	12.952	3.599	64.596
4	2000	72	10	7	70	4.429	0.226	22.581	2.807	0	7.952	2.82	63.677
				7.25	72.5	5.125	0.1968	19.678	2.8553	0	10.4285	3.2165	62.7873
1	3000	72	10	8	80	5.375	0.186	18.605	3	0	11.411	3.378	62.846
2	3000	72	10	7	70	5.286	0.189	18.919	2.807	0	10.571	3.251	61.512
3	3000	72	10	8	80	4.75	0.211	21.053	3	0	7.929	2.816	59.279
4	3000	72	10	8	80	5.75	0.174	17.391	3	0	11.357	3.37	58.609
				7.75	77.5	5.2903	0.19	18.992	2.9518	0	10.317	3.2038	60.5615

Appendix 6.6 Germination indices of Thiourea experiment

rep	**Thiourea**	**Time**	**seeds**	**grs**	**grp**	**mgt**	**mgr**	**gsp**	**unc**	**syn**	**vgt**	**sdg**	**cvg**
1	0	0	10	5	50	4	0.25	25	2.322	0	10	3.162	79.057
2	0	0	10	4	40	5	0.2	20	2	0	10	3.162	63.246
3	0	0	10	3	30	2	0.5	50	1.585	0	1	1	50
4	0	0	10	6	60	4.667	0.214	21.429	2.585	0	10.667	3.266	69.985
				4.5	45	3.9168	0.291	29.1073	2.123	0	7.91675	2.6475	65.572
1	1	24	10	7	70	5.714	0.175	17.5	2.807	0	10.571	3.251	56.899
2	1	24	10	8	80	5.25	0.19	19.048	3	0	10.786	3.284	62.555
3	1	24	10	8	80	5.5	0.182	18.182	3	0	10	3.162	57.496
4	1	24	10	6	60	5.667	0.176	17.647	2.585	0	10.667	3.266	57.635
				7.25	72.5	5.5328	0.1808	18.0943	2.848	0	10.506	3.2408	58.6463
1	2	24	10	7	70	4.857	0.206	20.588	2.807	0	11.81	3.436	70.751
2	2	24	10	8	80	6	0.167	16.667	3	0	8.571	2.928	48.795

3	2	24	10	6	60	5.167	0.194	19.355	2.585	0	13.367	3.656	70.762
4	2	24	10	7	70	4.857	0.206	20.588	2.807	0	11.81	3.436	70.751
				7	70	5.2203	0.1933	19.2995	2.7998	0	11.3895	3.364	65.2648
1	3	24	10	4	40	3.75	0.267	26.667	2	0	12.917	3.594	95.839
2	3	24	10	5	50	4.2	0.238	23.81	2.322	0	10.7	3.271	77.883
3	3	24	10	6	60	4.167	0.24	24	2.585	0	8.567	2.927	70.245
4	3	24	10	7	70	4.429	0.226	22.581	2.807	0	7.952	2.82	63.677
				5.5	55	4.1365	0.2428	24.2645	2.4285	0	10.034	3.153	76.911
1	1	48	10	6	60	4.833	0.207	20.69	2.585	0	14.167	3.764	77.873
2	1	48	10	5	50	5	0.2	20	2.322	0	17.5	4.183	83.666
3	1	48	10	6	60	5.833	0.171	17.143	2.585	0	12.167	3.488	59.796
4	1	48	10	5	50	5	0.2	20	2.322	0	17.5	4.183	83.666
				5.5	55	5.1665	0.1945	19.4583	2.4535	0	15.3335	3.9045	76.2503
1	2	48	10	4	40	4.5	0.222	22.222	2	0	11.667	3.416	75.903
2	2	48	10	5	50	4.2	0.238	23.81	2.322	0	10.7	3.271	77.883
3	2	48	10	4	40	3.75	0.267	26.667	2	0	12.917	3.594	95.839
4	2	48	10	3	30	4.333	0.231	23.077	1.585	0	17.333	4.163	96.077
				4	40	4.1958	0.2395	23.944	1.9768	0	13.1543	3.611	86.4255
1	3	48	10	4	40	3.75	0.267	26.667	2	0	12.917	3.594	95.839
2	3	48	10	3	30	4.333	0.231	23.077	1.585	0	17.333	4.163	96.077
3	3	48	10	5	50	4.2	0.238	23.81	2.322	0	10.7	3.271	77.883
4	3	48	10	4	40	3.75	0.267	26.667	2	0	12.917	3.594	95.839
				4	40	4.0083	0.2508	25.0553	1.9768	0	13.4668	3.6555	91.4095
1	1	72	10	7	70	4.857	0.206	20.588	2.807	0	11.81	3.436	70.751
2	1	72	10	5	50	4.2	0.238	23.81	2.322	0	12.7	3.564	84.85
3	1	72	10	7	70	4.857	0.206	20.588	2.807	0	11.81	3.436	70.751
4	1	72	10	6	60	4.833	0.207	20.69	2.585	0	14.167	3.764	77.873
				6.25	62.5	4.6868	0.2143	21.419	2.6303	0	12.6218	3.55	76.0563
1	2	72	10	6	60	4.667	0.214	21.429	2.585	0	10.667	3.266	69.985

2	2	72	10	5	50	4.6	0.217	21.739	2.322	0	13.3	3.647	79.281
3	2	72	10	4	40	3.75	0.267	26.667	2	0	12.917	3.594	95.839
4	2	72	10	3	30	2	0.5	50	1.585	0	1	1	50
				4.5	45	3.7543	0.2995	29.9588	2.123	0	9.471	2.8768	73.7763
1	3	72	10	4	40	3.75	0.267	26.667	2	0	12.917	3.594	95.839
2	3	72	10	6	60	4.5	0.222	22.222	2.585	0	9.5	3.082	68.493
3	3	72	10	5	50	4.2	0.238	23.81	2.322	0	10.7	3.271	77.883
4	3	72	10	4	40	3.75	0.267	26.667	2	0	12.917	3.594	95.839
				4.75	47.5	4.05	0.2485	24.8415	2.2268	0	11.5085	3.3853	84.5135

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LETTER TO THE EDITOR

The indispensable bond between Mazri Palm (*Nannorrhops ritchiana*) and the Indian Porcupine (*Hystrix indica*) leads them towards extinction!

Abdullah[1] · **Zahoor Ul Haq**[1] · **Shujaul Mulk Khan**[1]

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The Mazri Palm (*Nannorrhops ritchiana*) is one of the native palm species of Pakistan, Afghanistan, Iran, and Saudi Arabia. In southern Europe and southern and subtropical parts of America it is grown as an ornamental (Mahmood et al. 2017). Historically, the leaves and stems are remarkable source of mats, fences and house roofing (Goodman and Ghafoor 1992) and numbers of other handicrafts. Leaves alone are used to manufacture handicrafts such as hand fans, baskets, brooms, trays, prayer mats, storage boxes for grain, hot pots, hats, and sandals (Marwat et al. 2011). The reddish moss-like wool of the petioles of *Nannorrhops* is used as tinder. The seeds are utilized for manufacturing rosaries (Panhwar and Abro 2007) and the fresh fruits are edible. Dried parts of the plant are used as fuel wood as well. The local inhabitants collect leaves of the palm due to its utilization in handicrafts and others. Collection in huge amount of this plant is one of the main factors for the drastic decrease in its population. Keeping in mind the economic importance of this palm, the Government of Pakistan passed an act on the conservation of *Nannorrhops* namely "Kohat Mazri Control Act 1953" (http://kp.gov.pk/page/the-kohat-mazri-control-act-1953/page-type/rules) in 1953 where laws and rules were devised for the conservation of *Nannorrhops* in Pakistan in general and for the Kohat Division in particular (which then covered the whole southern Khyber Pakhtunkhwa). Regionally, it has been categorized as Endangered (EN) under the IUCN criteria. Murad et al. (2011) reported that in the Hazar Nao Forest of Malakand *Nannorrhops ritchiana* is on the verge of extinction due to over exploitation by the local population for commercial purposes.

Conservationists have also reported a tremendous decrease in the number of individuals of *Nannorrhops* over the past few decades in the region. Collection in huge amount of this plant for domestic as well as commercial purposes is one of the main eroding factors for its population. With this letter we report an important secondary reason for concern, the Indian Porcupine (*Hystrix indica*) which grazes the roots and leaves of *Nannorrhops*. The porcupine species use the roots mostly in the winter season for food. We continued our observations over the last 4 years in various regions of the Khyber Pakhtunkhwah Province and also interviewed local people where *Nannorrhops*' roots were observed/reported the

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Journal of Ethnobiology and Ethnomedicine

RESEARCH **Open Access**

Mazri (*Nannorrhops ritchiana* (Griff) Aitch.): a remarkable source of manufacturing traditional handicrafts, goods and utensils in Pakistan

Abdullah[1], Shujaul Mulk Khan[1*], Andrea Pieroni[2,3], Zahoor ul Haq[1] and Zeeshan Ahmad[1]

Abstract

Background: Mazri palm (*Nannorrhops ritchiana* (Griff) Aitch.) is a member of the family Arecaceae, native to Pakistan, Iran, Afghanistan, Oman, and Saudi Arabia. In Pakistan, it is used since long time for various purposes. This species plays a significant cultural and economic role in the daily lives of many rural areas in Pakistan and adjacent countries. However, the handcrafted products made up of this palm are often mainly known by specific local communities rather than by a broader range of people.

Methods: Eighty-six structured and semi-structured interviews were conducted from Mazri growing areas, villages, and markets of urban centers during the fieldwork that was conducted in diverse regions of Pakistan. Interviewees included 27 Mazri farmers, 17 locals retaining Traditional Knowledge in handcrafting Mazri palm (12 were men and 5 were women), 23 handicrafts experts (21 were men and 2 were women), and 19 sellers. The age of the informants ranged from 14 to 83 years. Study participants shared detailed information about various traditional utilizations of the Mazri palm.

Results: Mature leaves of Mazri palm are used to produce mats, baskets, hand fans, hats, cages, hot pots, salt pots, brooms, etc. in the sudy area. Hot pots, salt pots, mats, baskets, and ropes represent highly used items. The mats are used for various purposes like drying grains, performing prayers, sitting, and sleeping. As a whole, 39 different kinds of handcrafted products from the leaves were found. Our findings revealed also that other parts of the plant, ie. petioles, fruits, and bark, have been used, although more rarely, by the locals. The palm uses differ accordingly to the different cultural areas of Pakisitan, thus demonstrating that local cultural heritage significantly informs Traditional Knowledge and practices related to the use of Mazri palm. The findings suggest also that this plant represents a crucial resource for the livelihood of the local communities in dry areas of the western borders of Pakistan, starting right from the coastal areas of Baluchistan up to District Bajaur in the North, where other farming activities there are difficult due to drought conditions.

Conclusions: Traditional Knowledge about the sustainable utilization of Mazri palm is eroded in Pakistan among the younger generations due to rapid globalization and industrialization processes and appropriate strategies for revitalizing this heritage in a sustainable way should be urgently fostered.

Keywords: Mazri palm, Ethnobotany, Handicrafts, Pakistan, Biological conservation

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Title of Submitting Paper

Overcoming seed dormancy in the Mazri Palm; a sustainable way for its production at business scale

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Chapter 25

c0005 Utilization of three indigenous plant species as alternative to plastic can reduce pollution and bring sustainability in the environment

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ns0010 Abbreviations

di0010 **GoP** Government of Pakistan
di0015 **DPRI** Date Palm Research Institute
di0020 **NGOs** Non-Government Organizations
di0025 **WWF** World Wildlife Fund for Nature
di0030 **FAO** Food and Agriculture Organization

s0010 25.1 Introduction

p0035 Since the last three decades, unprecedented growth in the urban population has been experienced throughout the developing world. A 2.3% per year increase in the urban population of developing countries is expected till the year of 2030 (Brockerhoff, 2000; Wei et al., 2017; Yang et al., 2019). Mismanagement of the natural resources and use of artificial sources often generate pollutants of various kinds that in turn affect terrestrial as well as aquatic ecosystem either directly or indirectly (Capillo et al., 2018; Prokić et al., 2019; Khan et al., 2020a,b). Approximately the world's 54% plastic is formed of polyethylene and polypropylene polymers (Plastics Europe MRG, 2008; Bilal et al., 2016; Hahladakis et al., 2018). These plastics are not only used for the purpose of packaging but also used as protecting, and disposing commodities during handling all kind of goods and items. It creates number of challenges and problems to the survival of human population and environmental sustainability.

p0040 In modern world, plastics are considered as one of the mostly used materials (Kabasci, 2020). Production of plastics for commercial purposes was started in 1950s. Plastic production and its use dramatically increased from the past few decades. In 2016, plastic production was 330 million metrictons throughout the globe (Plastics Europe, 2017). China being the most populous country of the world produces maximum quantity that is about 60 million tons of plastics followed by the United States of America with 38, Germany 14.5, and Brazil with 12 million tons per year (Ritchie and Roser, 2018). Aquatic as well as terrestrial environment gets severely affected by plastic pollution (Horton et al., 2017). Various diseases such as breast and lung cancer, count and quality of sperm, genital and reproductive deformities are the most obvious problems happen due to plastic pollution (Verma et al., 2008). Ingestion of plastic and plastic particles also harms the aquatic flora and fauna such as algae, coral reefs, turtles, sharks, mammals, and birds (Galgani et al., 2019; Parton et al., 2019; Panti et al., 2019). The most serious and obvious impact of plastic pollution on the aquatic ecosystem reported that at least 260 species die due to ingestion and interaction with fossil fuel-derived plastic per year (Claro et al., 2019; Forrest et al., 2019).

Pakistan is also among such countries facing various types of problems in the shape of marine pollution, air pollution, climate change, flooding, etc. Annual production of plastic in Pakistan is estimated to be about 1.23 million tons. This huge amount of plastic waste for Pakistan is of big concern (Shah et al., 2008). Recently, in 2019, Ministry of Climate Change and Environmental Protection Agency of Pakistan banned the use of polythene shopping bags in the country and became the 128th country of the world who banned the use of polythene shopping bags. For the success of this positive step of the GoP, it is now necessary to produce biodegradable bags in massive quantities which would be environment friendly. p0045

In this chapter, we suggest use of biodegradable handicrafts and processed from plant fibers. Mazri palm p0050

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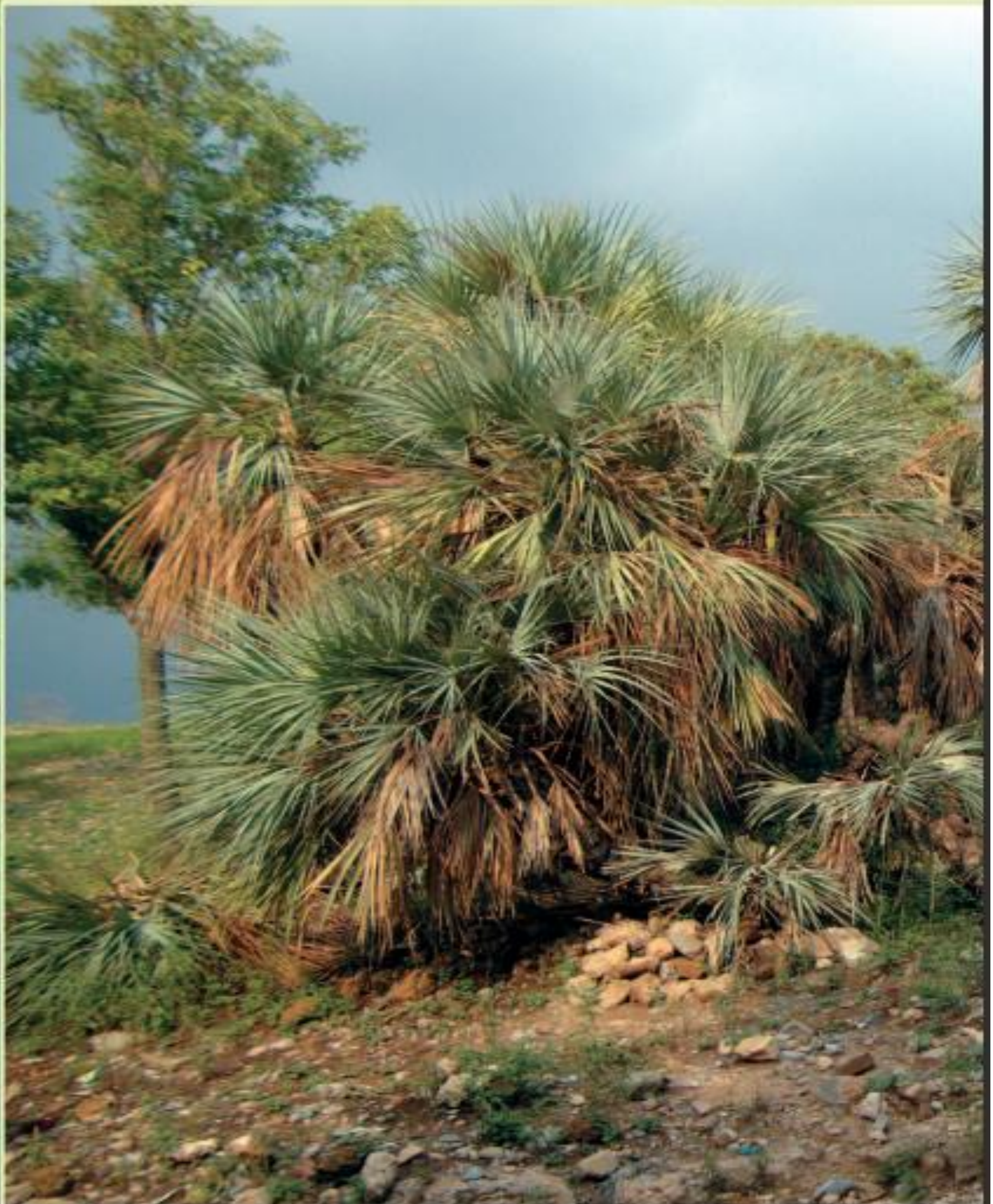

On the Trail of the *Mazri* Palm (*Nannorrhops ritchieana*) in Pakistan

ABDULLAH ABDULLAH[1,3], SHUJAUL MULK KHAN[1,2], SHAKIL AHMAD ZEB[1], SHAHAB ALI[1], ZAHOOR UL HAQ[1] AND HENRIK BALSLEV[3]

Mazri (Nannorrhops ritchieana) is an economically important palm in Pakistan, Iran, Afghanistan, Saudi Arabia and Oman. We studied 63 different mazri populations in the plains and hilly areas of northwestern Pakistan. We collected data on population ecology and plant species associated with the palm, and we took soil samples, all of which we hope will help its conservation and sustainable use. We observed its variation in leaf color, seed size and shape, which by some authors has been interpreted as evidence of more than one species. Securing its habitat is needed to conserve its genetic diversity and ecosystem services.

The palm *Nannorrhops ritchieana* (Griff.) Aitch., also known as the *mazri* palm, is native to Pakistan, Iran, Afghanistan, Saudi Arabia and Oman (Abdullah et al. 2020, Dransfield 2004). In Pakistan, *mazri* grows from sea level in semi-deserts along the Arabian Sea coast and it extends up the slopes of the Hindukush and Himalayan foothills to 1600 m elevation in subtropical forests (Champion et al. 1965, Abdullah 2019). Birds and cattle feed on the seeds facilitating their dispersal (Sayedi et al. 2022), but humans also disperse it, which gives the *mazri* a sporadic occurrence over its range (Fig. 1).

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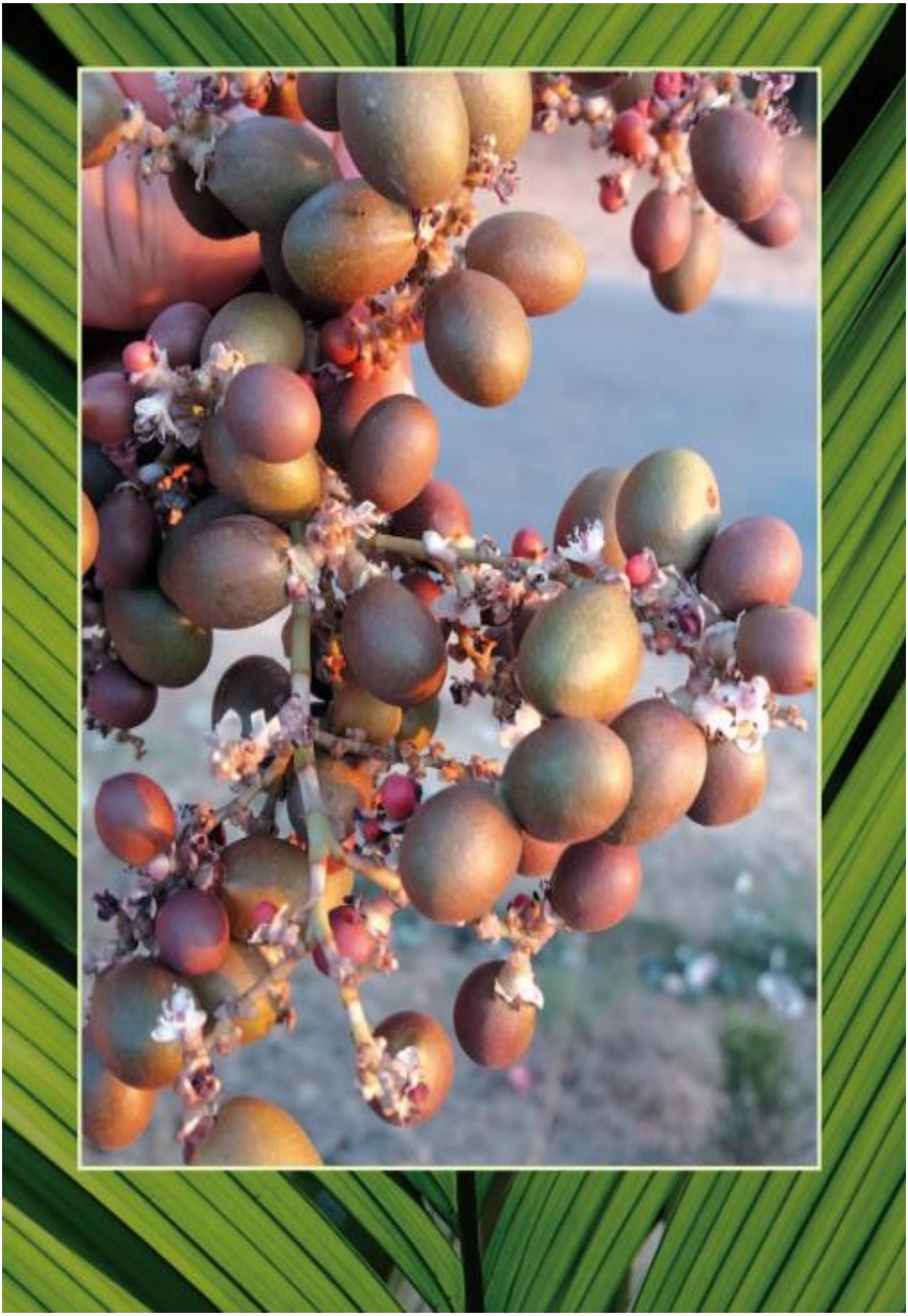
Mazri leaves are an important economic source of livelihood and cash income in different parts of Pakistan (Marwat et al. 2012, Abdullah et al. 2020, Ali et al. 2020, Abdullah et al. 2022). Handicrafts such as baskets, mats, hats, ropes, brooms, hand fans, bedsteads, hot pots



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