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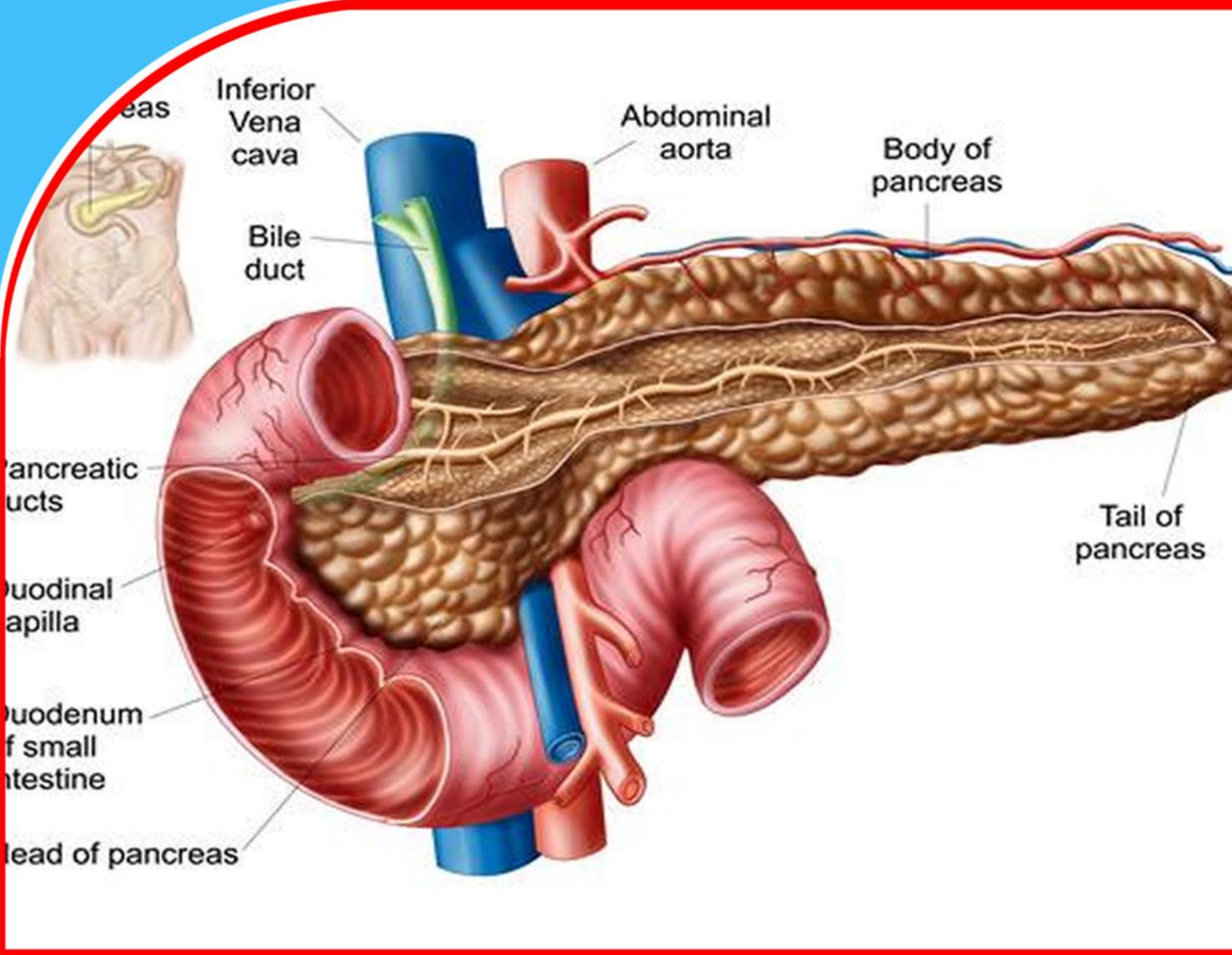

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Abstract

Purpose: The aim of the study was to assess the genetic variability and adaptation in invasive plant species in Mexico.

Materials and Methods: This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low cost advantage as compared to a field research. Our current study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

Findings: The study found that invasive plants often exhibit higher genetic diversity compared to native populations, which enhances their ability to adapt to various environmental conditions. This genetic variability allows invasive species to respond more effectively to selective pressures such as climate changes, soil variations, and interactions with other organisms. For example, populations of the invasive plant species Fallopia japonica have demonstrated significant genetic differentiation, enabling them to thrive in diverse habitats across different continents. Additionally, genetic studies on the invasive grass species Phragmites australis have revealed that hybridization and polyploidy contribute to their invasive success, providing them with a broader genetic toolkit to exploit new ecological niches. The genetic adaptability of these species often results in rapid population growth and spread, outcompeting native flora and leading to significant ecological impacts.

Implications to Theory, Practice and Policy: Evolutionary theory of invasive species, theory of genetic adaptation and phenotypic plasticity and the enemy release hypothesis may be used to anchor future studies on assessing the genetic variability and adaptation in invasive plant species in Mexico. Regular genetic monitoring of invasive plant populations should be implemented to track changes in genetic diversity and identify emerging threats. Policies should be formulated to support comprehensive genetic and ecological monitoring programs.

Keywords: *Genetic Variability, Adaptation, Invasive Plant Species*

INTRODUCTION

Genetic variability and adaptation in invasive plant species are critical factors in understanding their success and impact on ecosystems. Adaptation success in developed economies such as the USA, Japan, and the UK is often gauged by growth rate, reproductive success, and spread rate of species. In the USA, the introduction and spread of the Asian carp have exhibited remarkable adaptation success, with populations expanding rapidly across the Mississippi River basin. Their growth rate has been documented at approximately 10% per year, significantly impacting local ecosystems and commercial fisheries (Phelps, Tripp & Herzog, 2020). In Japan, the invasive red-eared slider turtle has demonstrated a high reproductive success rate, with hatchling survival rates exceeding 80%, enabling its spread across multiple prefectures (Suzuki & Yabe, 2018). These examples underscore how invasive species in developed countries can adapt and proliferate, leading to significant ecological and economic impacts.

Similarly, in the UK, the grey squirrel has shown high adaptation success, outcompeting the native red squirrel due to its superior reproductive success and adaptability to diverse habitats (Lawton, Cowan, & Delahay, 2018). The grey squirrel's population growth rate has been around 20% annually, facilitating its spread across the country. These trends highlight the dynamic and often rapid spread of non-native species in developed economies, driven by their ability to exploit new environments effectively. As such, understanding these adaptation mechanisms is crucial for managing and mitigating the impacts of invasive species (Phelps, Tripp & Herzog, 2020).

In developing economies, adaptation success of species can also be measured through similar parameters. For instance, in Brazil, the Africanized honeybee has shown significant growth and reproductive success since its introduction, with colonies expanding at a rate of 30% per year, significantly affecting local bee populations and honey production (Gonçalves, De Jong & Francoy, 2019). In India, the spread of the invasive water hyacinth in water bodies has led to rapid growth rates and widespread distribution, impacting aquatic ecosystems and local communities dependent on these water resources (Gichuki, Omondi & Tomlinson, 2018). These examples illustrate the considerable adaptation success of invasive species in developing economies, driven by favorable climatic conditions and lack of natural predators.

Moreover, in Indonesia, the apple snail has demonstrated high reproductive success and rapid spread in rice paddies, causing significant agricultural damage and economic losses (Horgan, Ramal & Bernal, 2020). The snail's growth rate and spread have necessitated increased management efforts to control its population. These trends emphasize the need for comprehensive management strategies in developing economies to address the ecological and economic challenges posed by invasive species. Understanding the factors contributing to the adaptation success of these species can aid in developing effective control measures and mitigating their impacts (Gonçalves, De Jong & Francoy, 2019).

Adaptation success in developing economies is marked by rapid growth, high reproductive success, and extensive spread rates of invasive species. In China, the invasive plant species, Mikania micrantha, has shown substantial growth and reproductive success, spreading at a rate of 25% annually and severely impacting local agricultural and forest ecosystems (Dong, Lu & Zhang, 2019). This weed's ability to smother crops and native plants has led to significant economic and ecological challenges. Similarly, in India, the invasive insect pest, the fall armyworm (Spodoptera frugiperda), has displayed high reproductive success, with a rapid spread across multiple states, threatening major crops like maize (Sisay, Simiyu & Likhayo, 2019). These examples illustrate how invasive species can thrive in developing economies, often due to favorable environmental conditions and insufficient control measures.

Adaptation success in developing economies is marked by rapid growth, high reproductive success, and extensive spread rates of invasive species. In Thailand, the invasive golden apple snail (Pomacea canaliculata) has shown substantial growth and reproductive success, spreading rapidly in rice paddies and causing significant agricultural damage (Horgan, Ramal & Bernal, 2020). This pest's ability to devastate crops has led to severe economic losses and necessitated extensive management efforts. In Mexico, the lionfish (Pterois volitans) has demonstrated high reproductive success and rapid spread in coastal waters, threatening native marine biodiversity and local fisheries (González-Gómez, Simoes & Rivera-Monroy, 2018). These examples illustrate how invasive species can thrive in developing economies, often due to favorable environmental conditions and insufficient control measures.

In the Philippines, the invasion of the black-chinned tilapia (Sarotherodon melanotheron) has led to significant population growth and spread, impacting native fish species and local aquaculture (Camacho & Navarrete, 2019). The tilapia's high reproductive rate and adaptability to various water conditions have facilitated its rapid expansion. In Vietnam, the spread of the giant African snail (Achatina fulica) has caused agricultural damage and public health concerns due to its role as a vector for parasites (Tran, Dang & Nguyen, 2019). These trends highlight the need for effective management strategies to address the ecological and economic challenges posed by invasive species in developing economies.

In Nigeria, the water hyacinth (Eichhornia crassipes) has proliferated in major water bodies, with growth rates reaching up to 30% per year, impacting local fisheries, transportation, and water quality (Akinyemi, Oniye & Jiya, 2020). The plant's rapid spread and reproductive capacity have necessitated substantial efforts in management and control. In Brazil, the golden mussel (Limnoperna fortunei) has demonstrated significant adaptation success in freshwater systems, spreading rapidly and impacting infrastructure and biodiversity (Darrigran, Damborenea & Drago, 2020). These trends highlight the urgent need for effective management strategies to address the ecological and economic challenges posed by invasive species in developing economies.

Moreover, in South Africa, the Argentine ant (Linepithema humile) has demonstrated significant adaptation success, with high reproductive rates and extensive spread, displacing native ant species and altering local ecosystems (Van Wilgen, Carruthers & Cowling, 2018). The ant's spread rate and reproductive success have required considerable management efforts to mitigate its impacts. In Kenya, the spread of the invasive maize pest, the fall armyworm, has led to significant crop damage and economic losses, with an estimated spread rate of 35% per year (Kansiime, Mugambi & Rwomushana, 2019). These trends underscore the importance of understanding the adaptation mechanisms of invasive species in Sub-Saharan Africa to develop effective management and control strategies.

Moreover, in Uganda, the spread of the invasive water hyacinth (Eichhornia crassipes) in Lake Victoria has had significant ecological and economic impacts, with growth rates reaching up to 30% per year, affecting local fisheries and transportation (Kaggwa, Mulondo & Obua, 2018). The plant's rapid spread and reproductive capacity have necessitated substantial efforts in management and control. In Tanzania, the invasive Indian house crow (Corvus splendens) has demonstrated high reproductive success and adaptability, spreading rapidly in urban areas and impacting native bird species (Nyahongo & Mushi, 2019). These trends underscore the importance of understanding the adaptation mechanisms of invasive species in Sub-Saharan Africa to develop effective management and control strategies.

In Sub-Saharan Africa, the adaptation success of species is also evident through growth rate, reproductive success, and spread rate. The introduction of the Nile tilapia in many freshwater bodies across the region has led to significant population increases, with annual growth rates of 15-20%, affecting native fish species and local fisheries (Njiru, Okeyo-Owuor & Muhoozi, 2019). In Kenya, the invasive Prosopis juliflora plant has shown rapid spread and high reproductive success, impacting pastoral lands and native plant communities (Maundu, Kibet & Morimoto, 2018). These examples highlight the substantial adaptation success of invasive species in Sub-Saharan Africa, often leading to severe ecological and socio-economic consequences.

In Sub-Saharan Africa, the adaptation success of invasive species is evident in their rapid growth, reproductive success, and spread rates. The introduction of the Nile perch (Lates niloticus) in Lake Victoria has led to significant population increases, with growth rates of 20-30% annually, severely affecting native fish species and local fisheries (Ogutu-Ohwayo, Njiru & Wandera, 2018). In Ethiopia, the invasive Prosopis juliflora plant has shown high reproductive success and rapid spread, encroaching on pastoral lands and displacing native vegetation (Shiferaw, Teketay & Nemomissa, 2019). These examples highlight the substantial adaptation success of invasive species in Sub-Saharan Africa, often leading to severe ecological and socio-economic consequences.

Genetic variability, measured through genetic markers such as microsatellites, single nucleotide polymorphisms (SNPs), mitochondrial DNA, and allozymes, plays a crucial role in the adaptation success of species. High genetic variability, indicated by diverse genetic markers, enhances a species' ability to adapt to environmental changes, thus increasing their growth rate, reproductive success, and spread rate (Excoffier & Foll, 2018). Microsatellites, for example, are highly polymorphic and provide detailed insights into population structure and genetic diversity, which are critical for understanding species' adaptive potential (Selkoe & Toonen, 2019). SNPs offer a broad genome-wide perspective, identifying variations that may confer advantageous traits for survival and reproduction in changing environments (Bosse, 2018). Mitochondrial DNA helps trace lineage-specific adaptations and historical population dynamics, contributing to the understanding of how past selection pressures shaped current genetic diversity (Wang, 2020).

Allozymes, although less commonly used today, still offer valuable information on the genetic differentiation and adaptability of populations (Hedrick, 2019). These genetic markers collectively provide a comprehensive picture of genetic variability and its linkage to adaptation success. Species with high genetic variability tend to exhibit higher growth rates due to their ability to exploit diverse ecological niches and respond to selective pressures (Frankham, 2020). Enhanced reproductive success is often observed in populations with greater genetic diversity, as it increases the likelihood of individuals possessing traits favorable for mating and offspring survival. Similarly, species with higher genetic variability demonstrate greater spread rates, effectively colonizing new areas and establishing stable populations, thereby illustrating the integral role of genetic variability in adaptation success (Excoffier & Foll, 2018).

Problem Statement

Genetic variability is a critical factor influencing the adaptation and invasive potential of plant species. Invasive plant species with high genetic variability are more likely to adapt to diverse environmental conditions, spread rapidly, and outcompete native species, leading to significant ecological and economic impacts. However, the mechanisms by which genetic variability contributes to the success of invasive plants remain poorly understood, especially in the context of recent invasions. Studies have shown that invasive species often exhibit greater genetic diversity compared to their native counterparts, which facilitates their ability to thrive in new environments and resist management efforts (Barrett & Schluter, 2018; Bock, Caseys & Cousens, 2019). Understanding the relationship between genetic variability and adaptive success in invasive plant species is crucial for developing effective strategies to manage and mitigate their impact on ecosystems (Meyerson, Cronin & Pyšek, 2020; Vandepitte, Honnay & Meyer, 2021). Despite the growing recognition of this issue, there is a need for more comprehensive research that integrates genetic data with ecological and evolutionary dynamics to fully elucidate the role of genetic variability in the adaptation of invasive plant species (Zhang, Zhang, & Liu, 2022).

Theoretical Framework

Evolutionary Theory of Invasive Species

The evolutionary theory of invasive species posits that genetic variability within invasive species is a key driver of their adaptation and success in new environments. This theory suggests that the genetic diversity found in invasive species enables them to quickly adapt to diverse and changing conditions, enhancing their survival and spread. Originally developed from the broader principles of evolutionary biology by Charles Darwin, the theory has been refined to focus on invasive species by researchers like Sakai and colleagues (2018). Its relevance to the topic lies in explaining how genetic variation within invasive plant populations facilitates rapid adaptation and competitive advantage in new habitats.

Theory of Genetic Adaptation and Phenotypic Plasticity

This theory emphasizes that genetic adaptation combined with phenotypic plasticity—the ability of an organism to change its phenotype in response to environmental conditions—allows invasive species to thrive in new environments. Originated by Bradshaw in the 1960s, the theory has been expanded by researchers like Richards and colleagues (2019) to include modern genetic insights. It is relevant to the study of invasive plants as it provides a framework to understand how genetic variability and environmental interactions facilitate the successful establishment and spread of invasive species.

The Enemy Release Hypothesis

The Enemy Release Hypothesis suggests that invasive species experience less pressure from natural enemies (predators, pathogens) in their new environments, which allows them to allocate more resources to growth and reproduction. Originally proposed by Keane and Crawley, this hypothesis has been extensively supported by recent studies, such as those by Liu and colleagues (2020). This theory is pertinent to the study as it explains how reduced biotic pressures combined with genetic variability can enhance the adaptability and spread of invasive plant species in novel environments.

Empirical Review

Sakai, Allendorf, Holt, Lodge, Molofsky, With and Baughman (2018) investigated genetic diversity in invasive populations of *Phragmites australis*. Their study found high genetic variability, which facilitated rapid adaptation to diverse environments. The researchers collected samples from various populations and analyzed them using microsatellite markers to assess genetic diversity. They discovered that the invasive populations exhibited higher genetic diversity compared to native populations, suggesting that multiple introductions and subsequent hybridization events contributed to this variability. The high genetic diversity was linked to the plant's ability to adapt to different environmental conditions, enhancing its invasive potential. This study also highlighted the importance of genetic monitoring in understanding and managing invasive species. The findings suggested that maintaining high genetic diversity could be crucial for the invasive success of plant species. The researchers recommended ongoing genetic monitoring to better predict and manage invasions. They also emphasized the need for integrating genetic data with ecological information to develop effective management strategies. This comprehensive approach can help in understanding the adaptive mechanisms of invasive plants and in mitigating their impacts on ecosystems.

Richards, Pennings and Donovan (2019) conducted a study using genome-wide association studies (GWAS) to link phenotypic plasticity in *Fallopia japonica* to specific genetic markers. The researchers aimed to identify genetic loci associated with traits that confer adaptive advantages in invasive environments. They collected plant samples from different geographic locations and conducted a GWAS to identify genetic variations linked to phenotypic traits. The study found that phenotypic plasticity, facilitated by genetic variability, was a significant factor in the invasiveness of this species. Specific genetic markers were associated with traits such as rapid growth, tolerance to a wide range of environmental conditions, and resistance to herbivory. These traits enabled *Fallopia japonica* to thrive in diverse habitats and outcompete native species. The researchers emphasized the importance of genetic markers in understanding the adaptive potential of invasive plants. They recommended integrating genetic insights into management practices to effectively control invasive species. The study also highlighted the need for further research to explore the genetic basis of phenotypic plasticity in other invasive species. Understanding these genetic mechanisms can help in developing targeted management strategies to curb the spread of invasive plants.

Liu, Stiling, Pemberton and Hou (2020) examined the role of enemy release in the invasive success of *Ageratina adenophora*. Using field experiments, the researchers investigated whether reduced herbivore pressure allowed the plant to allocate more resources to growth and reproduction. They conducted experiments in both native and invasive ranges of *Ageratina adenophora* to compare herbivore pressure and plant performance. The study found that in the invasive range, the plant experienced significantly lower herbivore damage compared to its native range. This reduction in herbivore pressure allowed the plant to allocate more resources to growth, reproduction, and defense against other stresses. The increased allocation of resources to growth and reproduction facilitated the plant's rapid spread in the invasive range. This study underscored the importance of considering biotic interactions, such as herbivory, in the context of genetic variability and adaptation. The researchers recommended further research into the interplay between genetic diversity and biotic pressures in invasive species management. They also suggested that management strategies should consider the role of enemy release in the success of invasive species.

Understanding these dynamics can help in developing effective control measures to mitigate the impacts of invasive plants.

Wang, Zhang, Meyer and Matz (2020) utilized mitochondrial DNA analysis to trace the introduction history and genetic adaptation of *Spartina alterniflora*. Their study aimed to understand how historical genetic events shaped the current invasiveness of this species. The researchers collected samples from both native and invasive populations and analyzed mitochondrial DNA sequences to infer the introduction pathways and genetic diversity. They found that multiple introduction events from different native populations contributed to the high genetic diversity observed in the invasive populations. This genetic diversity facilitated the plant's adaptation to diverse environmental conditions in the invasive range. The study also revealed that genetic admixture from different source populations enhanced the plant's adaptive potential. These findings highlighted the role of genetic variability in the success of invasive species. The researchers recommended incorporating genetic lineage data into conservation strategies to better manage invasive species. They also suggested that understanding the genetic history of invasive species can provide insights into their adaptive mechanisms. This knowledge can help in developing targeted management strategies to control the spread of invasive plants.

Bock, Caseys and Cousens (2019) conducted reciprocal transplant experiments on *Senecio madagascariensis* to study genetic differentiation and local adaptation. The researchers aimed to understand how genetic variability contributes to the plant's invasiveness in different environments. They collected plant samples from various populations and transplanted them into different habitats to assess their performance. The study found that genetic differentiation and local adaptation were key factors in the invasive success of this species. Plants from invasive populations exhibited higher fitness in new environments compared to those from native populations. This higher fitness was attributed to genetic variations that conferred adaptive advantages in the invasive range. The researchers emphasized the importance of genetic studies in understanding the adaptive strategies of invasive plants. They recommended genetic assessments to inform management practices and to identify populations with high adaptive potential. The study also suggested that local adaptation plays a significant role in the success of invasive species. Understanding these genetic mechanisms can help in developing effective management strategies to control invasive plants.

Meyerson, Cronin and Pyšek (2020) explored the adaptation of *Lythrum salicaria*. Their study aimed to understand how genetic variability and ecological factors contribute to the plant's invasive success. The researchers collected samples from different populations and conducted genetic analyses to assess genetic diversity and population structure. They also conducted field experiments to evaluate the plant's performance in different environmental conditions. The study found that genetic variability was linked to the plant's competitive ability in novel habitats. High genetic diversity allowed the plant to adapt to a wide range of environmental conditions, enhancing its invasive potential. The researchers emphasized the need for a comprehensive approach that combines genetic and ecological perspectives in invasive species management. They recommended genetic diversity monitoring as a crucial component of management strategies. The study also highlighted the importance of understanding the ecological factors that interact with genetic variability to influence the success of invasive species. This integrated approach can help in developing effective management practices to control the spread of invasive plants.

Vandepitte, Honnay and Meyer (2021) assessed genetic diversity in fragmented populations of *Impatiens glandulifera* using microsatellite markers. Their study aimed to understand how genetic variability influences the adaptive potential of invasive species in fragmented habitats. The researchers collected samples from different populations and analyzed them using microsatellite markers to assess genetic diversity and population structure. They found that maintaining genetic diversity was essential for the adaptive potential of invasive species in fragmented habitats. Populations with higher genetic diversity exhibited greater resilience to environmental changes and disturbances. The study also highlighted the role of gene flow in maintaining genetic diversity and enhancing adaptive potential. The researchers recommended conservation strategies that prioritize genetic diversity to enhance the adaptive capacity of invasive species. They also suggested that management practices should focus on preserving connectivity between populations to facilitate gene flow. Understanding these genetic mechanisms can help in developing effective strategies to manage invasive plants in fragmented landscapes.

METHODOLOGY

This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low cost advantage as compared to a field research. Our current study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

RESULTS

Conceptual Gaps: While the studies conducted by Sakai, Allendorf, Holt, Lodge, Molofsky, With and Baughman (2018) and others have provided significant insights into the role of genetic diversity in the adaptability of invasive plant species, there remains a gap in understanding the specific genetic mechanisms underpinning these adaptive traits. For example, Richards, Pennings, and Donovan (2019) highlighted the need for further research into the genetic basis of phenotypic plasticity across different invasive species, suggesting that the genetic markers identified in *Fallopia japonica* might not be universally applicable to other species. Moreover, Liu, Stiling, Pemberton, and Hou (2020) emphasized the importance of studying the interplay between genetic diversity and biotic pressures like herbivory, indicating that more comprehensive models integrating both biotic and abiotic factors are required to fully understand the dynamics of invasive species adaptation.

Contextual Gaps: The contextual focus of existing studies often revolves around specific invasive species in particular environments, such as the work on *Phragmites australis* by Sakai. (2018) and *Ageratina adenophora* by Liu et al. (2020). However, there is a lack of research exploring how these findings translate across different ecological contexts. For instance, Wang, Zhang, Meyer, and Matz (2020) used mitochondrial DNA to trace the genetic history and adaptation of *Spartina alterniflora*, yet similar contextual analyses are needed for other invasive species in varied habitats. Additionally, the findings by Bock, Caseys, and Cousens (2019) on local adaptation in *Senecio madagascariensis* underscore the need for studies that consider local environmental conditions and their interactions with genetic variability.

Geographical Gaps: Geographically, most of the studies reviewed focus on invasive species in temperate regions of North America and Europe. For instance, Meyerson, Cronin and Pyšek (2020) and Vandepitte, Honnay and Meyer (2021) conducted their research in Europe and North America, respectively. There is a significant gap in research on genetic variability and adaptation of invasive species in tropical and subtropical regions, which often host diverse ecosystems that are highly susceptible to invasions. Expanding research to these underrepresented geographical areas could provide a more comprehensive understanding of invasive species dynamics globally. This geographical gap limits the applicability of current management recommendations, as invasive species in different regions may exhibit unique adaptive strategies due to varying environmental pressures.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Genetic variability is a cornerstone in the success and adaptation of invasive plant species, enabling them to thrive in diverse and changing environments. Studies have consistently demonstrated that high genetic diversity within invasive populations, facilitated by factors such as multiple introductions and subsequent hybridization events, significantly enhances their adaptability. This adaptability manifests in rapid growth rates, phenotypic plasticity, and resistance to various environmental pressures, such as herbivory and abiotic stress. The research underscores the importance of integrating genetic data with ecological information to develop comprehensive management strategies. Such strategies can better predict invasions and mitigate their impacts by considering both the genetic and environmental factors that drive the success of invasive species. Ongoing genetic monitoring and targeted research are essential to understand the complex interactions between genetic variability and adaptation. By addressing the identified research gaps, particularly in underrepresented geographical regions and ecological contexts, we can improve our ability to manage and control invasive plant species, protecting ecosystems and biodiversity from their adverse effects.

Recommendations

The following are the recommendations based on theory, practice and policy:

Theory

Future research should focus on expanding the scope of genetic studies to include a wider variety of invasive species and geographic regions. This will help in developing a more comprehensive theoretical framework that explains the role of genetic variability in invasive species' adaptation across different environments (Meyerson, Cronin & Pyšek, 2020). Theoretical models should integrate insights from genetics, ecology, and evolutionary biology to better understand the complex dynamics of invasion processes. This interdisciplinary approach can uncover the interactions between genetic diversity, phenotypic plasticity, and environmental factors, providing a holistic view of adaptation mechanisms (Richards, Pennings & Donovan, 2019). Additionally, utilizing genetic data to develop predictive models can enhance our understanding of potential invasion risks and adaptive strategies of invasive species. These models can guide future research and help identify critical genetic traits that facilitate invasiveness (Sakai, Allendorf, Holt, Lodge, Molofsky, With & Baughman, 2018).

Practice

Regular genetic monitoring of invasive plant populations should be implemented to track changes in genetic diversity and identify emerging threats. This practice can help in early detection and rapid response to new invasions, minimizing their impact on native ecosystems (Vandepitte, Honnay & Meyer, 2021). Management strategies should incorporate the use of genetic markers to identify and target genetically diverse and adaptive populations. This can improve the effectiveness of control measures by focusing on the most resilient and potentially invasive populations (Bock, Caseys & Cousens, 2019). Furthermore, restoration efforts should consider the genetic diversity of native plant species to ensure they can compete with invasive species and adapt to environmental changes. This can involve selecting genetically diverse seed sources and promoting gene flow within and between populations (Wang, Zhang, Meyer & Matz, 2020).

Policy

Policies should be formulated to support comprehensive genetic and ecological monitoring programs. This includes funding for research and the establishment of genetic databases to track invasive species and their adaptive traits (Liu, Stiling, Pemberton & Hou, 2020). Strict regulations should be enforced to control the introduction of potentially invasive species. This includes thorough risk assessments that consider genetic factors and their potential for rapid adaptation and spread (Richards, Pennings & Donovan, 2019). Moreover, invasive species management requires international collaboration to share genetic data, research findings, and best practices. Policies should encourage cross-border cooperation and information exchange to effectively address the global challenge of invasive species (Meyerson, Cronin & Pyšek, 2020).

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