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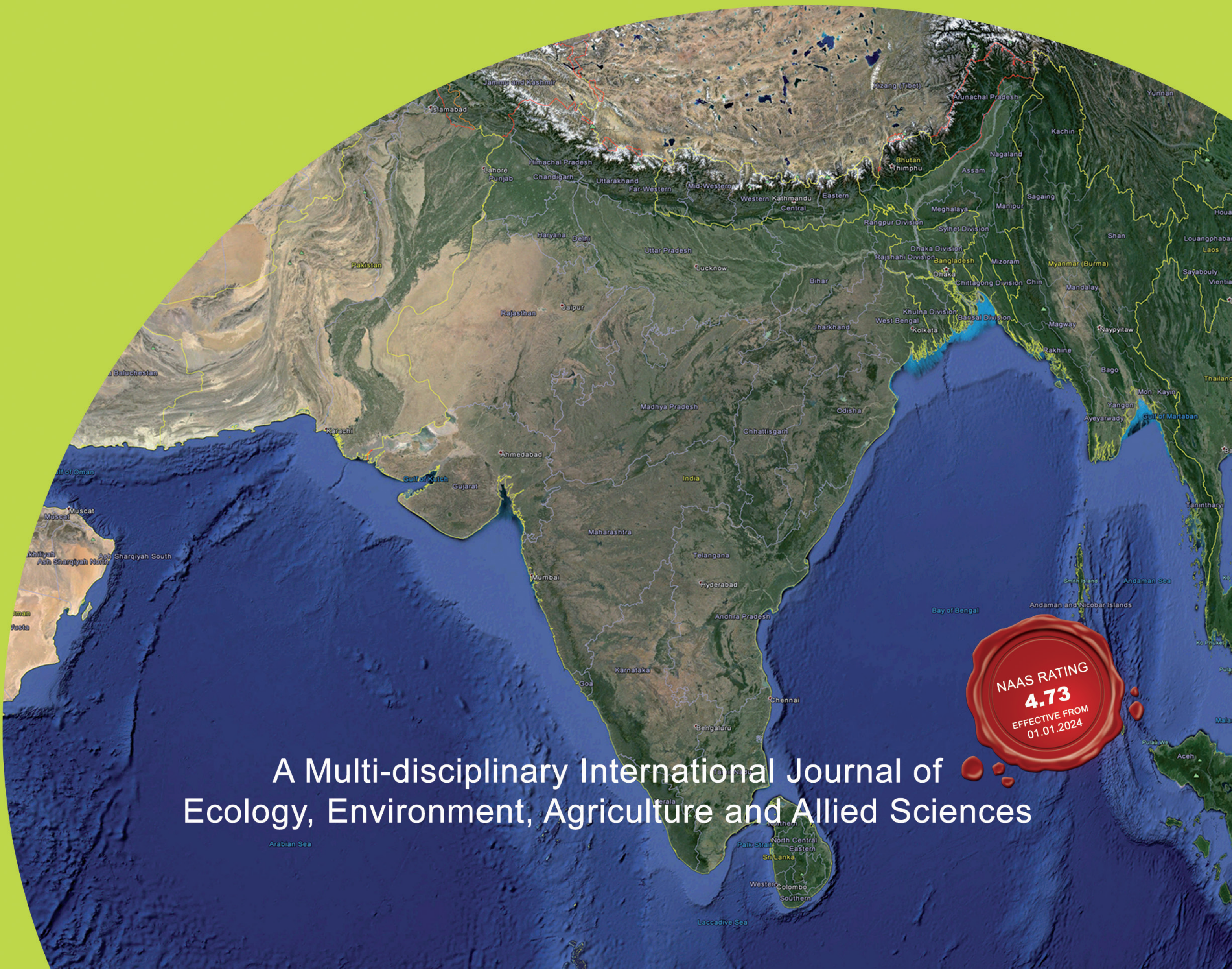

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Logo Description: It symbolizes an elephant within an ecological frame of peace and harmony moving towards prosperity and posterity.

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CONTENTS

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Ecosystem services provided by water birds in wetlands: A review

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ABSTRACT

Water birds have important ecological functions in wetland habitats, contributing significantly to biodiversity and providing a variety of ecosystem services. This review summarizes current research on water birds' ecological functions in wetland settings, with a focus on their contributions to providing, regulating, cultural, and supporting services. Water birds have an important role in nutrient cycling, seed dissemination, pest management, and trophic regulation, as well as functioning as bio indicators for ecosystem health. Furthermore, they have cultural and recreational significance, promoting ecotourism and traditional customs. The review focuses on how water bird populations influence wetland dynamics through foraging, migration, and nesting activities. Threats to water birds, such as habitat degradation, climate change, and human disturbance, are also examined in light of their cascading impacts on wetland functions.

Key words: Biodiversity, ecological roles, habitat management, wetland conservation

INTRODUCTION

Wetlands are extremely productive ecosystems that offer a number of vital services, such as carbon sequestration, flood control, water filtration, and vital habitat for biodiversity (Mitsch and Gosselink, 2015). As an essential part of wetland biodiversity, water birds have a significant impact on how these ecosystems are structured and function. These birds play an important role in ecological processes like seed dispersal, nitrogen cycling, and the preservation of wetland habitat diversity, all of which sustain a wide variety of other species. Birds that use aquatic environments for roosting, nesting, and foraging are generally referred to as water birds. Anseriformes (ducks, geese), Ciconiiformes (herons, egrets), Gruiformes (rails, cranes), Charadriiformes (shorebirds), and Pelecaniformes (pelicans) are among the many bird orders represented in the diverse group of water birds. According to Gauthier and Eldridge (2018), these species have developed unique adaptations for living in and around wetlands, viz webbed feet for swimming, long bills for probing dirt, and specialized plumage for insulation in cold water conditions. Water birds play a crucial role in wetland food webs, by regulating plant and animal populations through their diverse eating preferences, which range from herbivory to piscivory (Boerner et al., 2020). The trophic dynamics of wetland ecosystems depend heavily on water birds. They serve as both food for larger predators (such as raptors and carnivorous animals) and predators, feeding on aquatic invertebrates, small fish, and vegetation (Klein, 2016). Their actions affect prey populations and preserve trophic structures, which support the ecological balance of wetlands. Large waterfowl, like ducks and geese, for instance, can change the distribution and amount of wetland vegetation, which in turn impacts the food sources that are accessible to other creatures (Jongman et al., 2019). Apart from their feeding habits, water birds also play a role in the chemical and physical processes that occur in wetlands. Through nutrient excretion, guano deposition and sediment disturbance, their feeding and breeding activities boost biodiversity and primary productivity by redistributing nutrients within the environment (Williams et al., 2017).

Another significant ecological function of water birds is seed dissemination. In order to promote the connectedness of wetland plant communities and aid in the colonization of new habitats, several species, particularly waterfowls transport seeds from one location to another (Van der Valk and Davis, 2018). By guaranteeing the survival of plant species that depend on water birds for dispersal, this activity can contribute to the preservation of plant variety and ecosystem stability in wetlands (Guillemain et al., 2017). Furthermore, certain water bird species take part in behaviors that physically change wetland environments, like changing plant growth or establishing open water areas, which might help other wildlife species (Raab et al., 2020).

Because of their sensitivity to environmental changes, water birds also serve as bio indicators of the health of wetland ecosystems. Since they are frequently the top predators in wetland food webs, their distribution and abundance can be used to gauge the habitat's general health, including pollution levels, water quality, and food resource availability (Niemelä et al., 2019). Water bird population monitoring over an extended period can yield important information about how anthropogenic activities, habitat degradation, and climate change affect wetland ecosystems (Hollis et al., 2021). For example, decreases in water bird populations frequently indicate the beginning of habitat loss or wetland eutrophication, both of which have detrimental effects on ecosystem functioning (Liu et al., 2018).

Water birds face many risks despite their ecological importance, most of which are caused by human activity. One of the main reasons why water bird populations are declining worldwide is wetland degradation brought on by drainage, urbanization, and agriculture (Sutherland et al., 2017). Another significant issue is climate change, which has an impact on many species' food availability, mating success, and migration timing (Van der Jeugd et al., 2018; Zhang et al., 2020). Therefore, the preservation and restoration of wetland habitats, as well as the control of environmental stressors that affect wetland ecosystems, are closely related to the conservation of water birds.

The aim of this review is to present a thorough overview of the various functions that water birds perform in wetland environments. In addition to analyzing their potential as bio indicators of wetland health, it investigates their roles in trophic dynamics, nitrogen cycling, habitat alteration, and seed distribution. It covers the different risks that water birds face and the significance of conservation measures to guarantee both their survival and the sustainability of the wetlands they call home. Through this investigation, we hope to draw attention to the vital role that water birds play in preserving the biological integrity of wetlands and the necessity of protecting them in view of the continuous environmental threats.

OVERVIEW OF WETLAND ECOSYSTEM

According to Mitsch and Gosselink (2015), wetlands are distinct, dynamic ecosystems that support a wide range of species, perform vital ecological tasks, and varied ecosystem services. They are described as regions that are constantly or seasonally saturated with water and that are home to a range of vegetation types, such as floating, submerged, and emergent plants (Dugan, 1990). From the Arctic tundra to tropical regions, wetlands can be found in every temperature zone. They range in size from tiny ponds to vast marshes, bogs, and estuaries. The anoxic conditions caused by the wet soils that define these habitats have an impact on the kinds of plants and animals that can flourish there. Wetlands are classified into several categories based on their hydrology, vegetation, and ecological functions, with two major types being freshwater wetlands (e.g., marshes, swamps, and bogs) and coastal wetlands (e.g., estuaries, mangroves, and tidal flats) (Keddy, 2010).

They are often classified further into palustrine, lacustrine, and riverine wetlands, depending on their connection to water bodies such as lakes or rivers (Cowardin et al., 1979). The hydrological and biogeochemical characteristics of wetlands create a productive environment for diverse species, making them one of the most biologically rich ecosystems on earth (Mitsch & Gosselink, 2015). Wetlands often act as transition zones between terrestrial and aquatic habitats, supporting a high degree of biodiversity, including a variety of plant species, invertebrates, fish, amphibians, and birds (Davidson, 2014). In particular, water birds are key components of wetland biodiversity and play an important role in shaping the structure and function of these ecosystems.

Water birds participate in a variety of ecological processes that enhance ecosystem resilience and productivity, water birds are essential to the health and operation of wetland ecosystems. Water birds can improve primary productivity and preserve water quality by transferring nutrients within and between aquatic and terrestrial environments through their foraging activities (Gunnarsson et al., 2018). Furthermore, a variety of water bird species serve as seed dispersers, which promotes plant colonization and preserve the diversity of wetland vegetation (Wenny et al., 2016). As top predators in wetland food webs, they aid in controlling fish and aquatic invertebrate populations, which can prevent ecological imbalances and manage pest outbreaks (Jefferies et al., 2017). By upsetting sediment layers while feeding, water birds also influence sediment dynamics by facilitating the release of nutrients and oxygen that are advantageous to wetland plants (Batzer and Boix, 2016). Furthermore, water birds are important bio indicators; variations in their numbers and habits can serve as early warning signs of environmental deterioration and frequently indicate changes in the health of wetland ecosystems (Ma et al., 2020). Water birds serve cultural ecosystem services in addition to ecological ones by offering chances for leisure, bird watching, and environmental education, all of which can encourage conservation and public participation. Because of their diverse functions, water bird populations must be protected in order to preserve biodiversity and the numerous ecosystem services that wetlands offer.

Kumar et al. (2022) highlighted the ecological significance of urban green spaces as waterbird refuges by reporting 124 bird species at Delhi's National Zoological Park, New Delhi. Odisha surveys, like the one by Patnaik et al. (2023), found 46 species close to Govt. (Auto.) College, Angul, demonstrating how urban and semi-urban wetlands support bird biodiversity in spite of human-induced stressors. 38 bird species were recorded in another study conducted in Paradip, Odisha, highlighting the necessity of conservation measures in port cities where wetland ecosystems are at risk (Mohanty and Das, 2024). Additionally, Singh and Verma (2021) observed the Red-Wattled Lapwing's adaptation to urban nesting sites in Dehradun, illustrating both the resilience of some water bird species and the urgent need to protect wetlands amid urban expansion. Together, these studies reinforce the vital connection between wetland conservation and sustaining the essential ecosystem services provided by water birds.

Ecological functions of wetlands

Important ecological services including carbon storage, flood control, water filtering, and wildlife habitat are all provided by wetlands as illustrated in Fig. 1. By capturing pollutants, sediments, and nutrients before they enter bigger water bodies, wetlands may filter and purify water, which is one of its most crucial roles (Gosselink and Turner, 2009). This role is especially crucial for minimizing the consequences of water pollution from urban runoff and agriculture, as well as for lowering the eutrophication of freshwater systems. Additionally, by collecting surplus water during times of heavy rainfall or snowmelt, wetlands serve as natural flood barriers (Mitsch and Gosselink, 2015). By absorbing and retaining carbon dioxide from the atmosphere, wetlands also act as carbon sinks. Wetland soils, especially peat lands, are important for mitigating climate change because they store a lot of carbon over extended periods of time (Worrall et al., 2018).

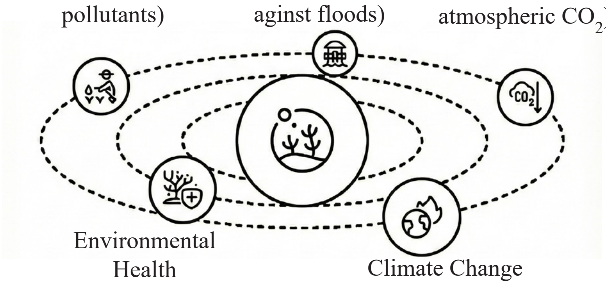

Fig. 1. Vital roles of wetlands in the ecosystem

Additionally, wetlands are essential to preserving biodiversity. Many species, especially migratory water birds, use them as nesting, feeding, and resting grounds. From grazing in nutrient-rich wetland waters to nesting in marshes and swamps, many water bird species depend on wetlands throughout their life cycles. High degrees of endemism are also supported by wetlands, as certain species have adapted to the particular environmental circumstances found in the wetlands (Batzer and Boix, 2016). Wetlands are therefore protected by international agreements like the Ramsar Convention, which acknowledges the value of wetlands for the preservation of water birds and other species, and are regarded as hotspots for biodiversity (Ramsar Convention Secretariat, 2013).

Wetland degradation and threats

Wetlands are among the most endangered habitats in the world, despite their ecological significance. Urbanization, agricultural growth, and industrial development are some of the causes that contribute to wetland loss and degradation (Davidson, 2014). Large wetland areas have been destroyed due to drainage for agriculture and land reclamation, especially in temperate regions where wetlands have been turned into cropland or urban development (Keddy, 2010). Along with disrupting the biodiversity of these habitats, the conversion of wetlands for human use results in the loss of vital ecosystem services including flood control and water filtration.

Wetland ecosystems are also seriously threatened by climate change. Wetland hydrology and plant communities are being impacted by rising temperatures, changed precipitation patterns, and a rise in the frequency of extreme weather events (Zhang et al., 2020). The distribution of wetland species, such as water birds that depend on certain wetland conditions for breeding and foraging, may be impacted by shifts in the timing and duration of seasonal water levels. Furthermore, the sustainability of wetlands may be further threatened by higher evaporation brought on by rising temperatures, which could worsen water scarcity in some areas (Batzer and Boix, 2016). Wetlands are also seriously threatened by pollution from sewage, industry, and agricultural runoff. Eutrophication, which lowers oxygen levels and promotes the growth of toxic algal blooms, can result from nutrient pollution, especially those caused by nitrogen and phosphate (Smith et al., 2016). Water bird populations that depend on aquatic invertebrates and plants for sustenance are also negatively impacted, as is the food chain (Liu et al., 2018).

Wetlands confront more subtle concerns than hydrological change and loss of area. The diversity and number of water birds are decreased by invasive species, which include both plants (like smooth cordgrass and water hyacinth) and predators (like non-native animals). These species also disrupt the structure of habitats, decrease or alter the availability of food, and increase nest predation (Zhao et al., 2018; Nordstrom, 2020). Growing amounts of micro plastic pollution in wetland sediments have also been reported in recent research; these plastics can alter the structure of microbial communities, interfere with plant root function, and eventually decrease wetlands' ability to absorb carbon (Wang et al., 2022; Liu et al., 2023). Additionally, freshwater hydrophytes are being stressed by saline intrusion brought on by sea level rise or changed freshwater inflows, which is also changing the makeup of aquatic invertebrates and vegetation. These changes have an impact on water bird nesting and foraging. Emerging risks also come from chemical contaminants (heavy metals, endocrine disruptors, and medications) and shifting water chemistry (from increased nutrients plus changed salinity), which frequently work in concert (Smith et al., 2016; Zhang et al., 2020). The cumulative effect of these challenges, especially in light of the accelerated climate change, may seriously impair ecosystem functions and put many water bird species in threat that depend on wetlands.

DIVERSITY AND FUNCTIONAL CLASSIFICATION OF WATER BIRDS

Diversity of taxa

Numerous species of water birds are adapted to a variety of wetland habitats, demonstrating the taxonomic richness of this group. They fall under the following general categories:

i. Ducks, geese, and swans are members of the Anseriformes family, which is mostly herbivorous or omnivorous and feeds on water plants, seeds, and invertebrates.

ii. Charadriiformes family: This group includes gulls and shorebirds. These animals are frequently piscivorous or insectivorous, helping to regulate insect populations and feeding on tiny fish.

iii. The family Ciconiiformes includes carnivorous animals such as herons, egrets, and ibises that eat fish, amphibians, and invertebrates.

Functional classification

Primary producers

Although they are uncommon, some water birds feed aquatic plants with their droppings, which helps with primary production.

Primary consumers

Herbivorous water birds, like several duck species, impact the dynamics of plant communities by consuming aquatic plants and debris.

Secondary consumers

Many shorebirds and other insectivorous and omnivorous species help regulate insect populations and aid in the cycling of nutrients.

Tertiary consumers

As apex predators in their own niches, carnivorous animals such as kingfishers and herons control fish and amphibian populations.

Seed dispersers

A variety of water birds aid in the spread of seeds, especially those of aquatic plants, which promotes plant diversity and regrowth.

Nutrient cyclers

Water birds are essential nutrient cyclers, moving nutrients from one trophic level to another and increasing ecosystem productivity through their feeding and excretion.

Bio-indicators

Kingfishers, which are piscivorous and frequently act as bio indicators of wetland quality because of their sensitivity to environmental changes, belong to the Coraciiformes family.

Ecological roles

Beyond their feeding habits, water birds have a variety of ecological responsibilities.

Habitat engineers

Some species, like some ducks, build nesting places that change the wetland's physical composition, which affects the amount of habitat available to other species.

Bio-indicators

Water birds are bio indicators that show the health of wetland ecosystems because of their sensitivity to environmental changes. Water bird population declines frequently indicate worsening habitat conditions.

Cultural and economic significance

In many cultures, water birds are highly valued culturally, and through hunting and bird watching, they support local economies.

Conservation status

Water bird species' conservation status

varies around the world, and many are threatened by hunting, pollution, habitat loss, and climate change. The wetland conservation is crucial for safeguarding water bird populations, according to international agreements like the Ramsar Convention. To guarantee these species' existence and the wellbeing of wetland ecosystems, efforts are made to restore habitat, reduce pollution, and implement sustainable management techniques.

ECOLOGICAL FUNCTIONS OF WATER BIRDS IN WETLAND ECOSYSTEMS

Water birds contribute to the biological balance and well-being of wetland habitats through a variety of roles. Their behaviors affect a number of ecological processes, such as species interactions, habitat architecture, and nutrient cycling.

Energy flow and nutrient cycling

The cycling of nutrients in wetland habitats depends on water birds. They aid in the movement of nutrients between trophic levels by consuming a wide range of species, such as tiny fish, invertebrates, and aquatic plants. By returning nutrients to the soil and water, their excretions improve the ecosystem and aid in primary production. Wetland ecosystems become more productive as a result of this process, ranking among the planet's most biologically productive areas.

Dynamics of vegetation and seed dispersal

Numerous water bird species aid in the establishment of aquatic and riparian plants by dispersing seeds. Through eating and subsequent defecation, the fruits and seeds they consume are carried to new sites. This seed movement influences the structure and succession of plant communities by encouraging plant diversity and the growth of vegetation in different areas of the marsh.

Habitat structure and engineering

Water birds can act as habitat engineers, modifying their environment in ways that create or alter habitats for other species. For instance, the feeding activities of certain water birds can influence the growth patterns of aquatic vegetation, affecting the structure of the habitat. Additionally, their nesting behaviors can create microhabitats that support a variety of other organisms, contributing to the overall biodiversity of the wetland.

Bio-markers of the health of ecosystems

The sensitivity of water birds to environmental changes makes them useful bio indicators of the health of wetlands. Changes in habitat, contaminants, and water quality can all be indicated by fluctuations in water bird numbers. Keeping an eye on these populations can help guide conservation and management plans and offer important insights into the ecological health of wetlands.

Regulation of disease and pest control

By consuming insects and other invertebrates that can harm marsh flora, certain species of water birds help control pests. Water birds contribute to the preservation of the ecosystem's equilibrium by controlling these populations. Additionally, because they have an impact on disease vector populations, their existence may have an impact on the prevalence of diseases inside the wetland.

Contributions to culture and the economy

Water birds have cultural and economic value in addition to their ecological duties. They are essential to many customs and cultural behaviors, particularly in societies that depend on wetlands for their life and nutrition. Since bird watching is a common pastime in wetland areas, water birds economically support ecotourism. This creates revenue and increases understanding of the value of preserving wetlands.

THREATS TO WATER BIRD POPULATION AND WETLAND ECOSYSTEM

Despite playing a vital role in wetland ecosystems, water birds are threatened in many ways, endangering both their numbers and the health of the marshes they live in. Anthropogenic activity, climate change, and environmental degradation are the main causes of these hazards. Designing successful conservation plans and guaranteeing the long-term sustainability of these habitats depend on an understanding of the main risks to both water birds and wetland ecosystems.

Degradation and loss of habitat

The biggest danger to water bird populations is probably habitat loss. Due to their extreme vulnerability to human activity, many wetlands have been drained or transformed for infrastructure, urbanization, or agricultural purposes. Important habitats for water birds to breed, feed, and nest have been destroyed as a result of wetland drainage for agricultural growth. Water bird populations suffer when wetlands are lost because there are fewer food sources, safe nesting grounds, and migratory stops available (Davidson, 2014). Invasive species, pollution, and hydrological changes can also cause wetland deterioration. Wetlands' natural water levels can be changed by dams, irrigation systems, and urban development, which can impact the flora and water birds' access to food (Keddy, 2010). The entire wetland ecology may eventually be impacted as a result of the disturbance of plant and animal groups.

Climate change

The threat posed by climate change to wetland habitats and the animals that rely on them is intricate and multidimensional. Wetland hydrology is already being impacted by changes in temperature, precipitation patterns, and the frequency of extreme weather events. Many water bird species that rely on particular water levels for nesting may experience disruptions in their breeding cycles due to rising temperatures that can change the timing and severity of wetland flooding and drying cycles (Van der Jeugd et al., 2018). Furthermore, in some areas, water scarcity can be made worse by greater evaporation brought on by warmer temperatures leading to reduction of wetland areas. Because many fish and aquatic invertebrate species are sensitive to temperature fluctuations, climate change may potentially result in changes in the availability of food sources (Zhang et al., 2020). Water birds may have to relocate or adjust their eating habits as a result of these shifts in the availability of food, which could result in population decreases.

Pollutants and contaminants

Water bird populations and wetland ecosystems are seriously threatened by pollution. Numerous pollutants, such as heavy metals, pesticides, medications, and nutrients (phosphorus and nitrogen), are introduced into wetland waterways via urban sewage, industrial discharges, and agricultural runoff. Eutrophication, which lowers oxygen levels and encourages the growth of toxic algal blooms, can result from an excess of nutrients from agricultural runoff (Smith et al., 2016). These blooms have the potential to produce hypoxic conditions, which would destroy aquatic species and decrease the amount of food available to water birds. Furthermore, pollutants like pesticides and heavy metals build up in the food chain and can harm water bird populations. Birds that consume tainted water or food may experience immune system weakness, infertility, or even death. These compounds can negatively impact entire populations through long-term bioaccumulation, which lowers species variety and richness in wetland habitats (Zhang et al., 2020).

Invasive species

Wetland ecosystem biodiversity is seriously threatened by invasive species. The ecological balance of wetland ecosystems can be upset by non-native species that outcompete or prey on local plants and animals. For instance, native plant species that are crucial for water bird foraging and breeding may be displaced by invasive plants like Typha (cattails) and *Phragmites australis* (common reed), which can take over wetland vegetation (Keddy, 2010). The thick monocultures that these invasive plants frequently create limit the variety of habitats available to water birds.

Hunting and overharvesting

Other hazards to water bird populations include hunting and overharvesting, especially in areas where hunting waterfowl is commercially or culturally significant. Even while hunting laws have been put in place in many nations to manage water bird populations and stop overhunting, fragile species are still at risk from illicit hunting and uncontrolled harvests. Population reductions can result from overhunting, especially during migratory times, especially for species that are already under stress from the environment or have sluggish rates of reproduction (Van der Jeugd et al., 2018). Hunting can also change how water birds use wetland habitats and interfere with their migration patterns. Hunting pressure may cause some water birds to avoid particular locations, which can result in the loss of vital habitats and the displacement of entire populations (Sutherland et al., 2017).

Inadequate conservation and management efforts

In order to keep wetland ecosystems healthy and in balance, water birds are essential. They serve as bio indicators of ecosystem health and aid in seed dissemination, nutrient cycling, and pest control. Nevertheless, conservation and management initiatives for water birds and their habitats continue to be inadequate and dispersed, despite their ecological significance.

CONSERVATION AND MANAGEMENT OF WATER BIRDS AND WETLANDS

Habitat protection and restoration of protected areas

Important habitats are protected when wetlands are designated as national parks, Ramsar areas, or reserves (Ramsar Convention Secretariat, 2016). Restoration Projects: Restoring habitat quality and hydrological functions is facilitated by rewetting drained wetlands and eliminating invasive species (Zedler, 2000).

Sustainable land use and buffer zones for pollution control

Planting vegetation buffers around wetlands lowers nutrient runoff. Regulation: Reducing contamination is aided by the implementation of laws governing the use of pesticides and pollutants.

Climate change adaptation strategies

Wetland connectivity Restoring and maintaining habitat corridors makes it easier for animals to migrate in response to changes in the climate. Managed Realignment: Coastal habitats are preserved by permitting wetlands to move inland when sea levels rise (Craft et al., 2009).

Research and monitoring

Early indicators of ecosystem stress are found by routine population and breeding success monitoring (Gregory et al., 2004). Citizen Science: Data collection and awareness are improved when communities get involved in bird watching and reporting. Research: Adaptive management is informed by the ecology and response to threats of species. Sustainable Agriculture: Reducing pollution and habitat loss by promoting wetland-friendly farming methods.

Community engagement and education

Awareness Programs: Educating the public about the ecological value of water birds and wetlands fosters stewardship. Involving Local Communities: Incorporating traditional knowledge and providing incentives encourages sustainable use.

CASE STUDIES

The United States' Chesapeake Bay

Numerous water bird species, such as colonial breeding herons and migratory ducks, can be found in the Chesapeake Bay (Fig. 2). Water bird numbers and water quality have increased as a result of restoration initiatives that emphasize habitat improvement and nutrient reduction (Kemp et al., 2005).

Fig. 2. Chesapeake Bay in United States (Chesapeake Bay Foundation)

Bangladesh and India's Sundarbans mangrove forest

The Sundarbans, which are home to a distinctive group of water birds, are threatened by both human exploitation and sea level rise as given in Fig. 3. To preserve biodiversity, conservation programs integrate community-based management with habitat protection (Giri et al., 2015).

Fig. 3. Mangrove forest (https://whc.unesco.org/en/list/798/)

Botswana's Okavango delta

During seasonal floods, this inland delta is home to significant colonies of water birds. Despite mounting pressures, ecological integrity has been preserved because of sustainable tourism and stringent wetland restrictions (McCarthy et al., 2000) as illustrated in Fig. 4.

Fig. 4. Botswana's Okavango delta (https://www.tripsavvy.com/guide-to-okavango-delta-in-botswana-1454194)

CONCLUSION

Water birds are essential to the structure, function, and biodiversity of wetland ecosystems in a variety of ways. Due to their varied adaptations, they may take advantage of a variety of wetland habitats across the globe, making significant contributions to ecosystem functions such as trophic regulation, vegetation dynamics, seed dissemination, and nutrient cycling. Often referred to as the "kidneys of the landscape," wetlands depend on these birds to maintain ecological services that enhance human well-being and biodiversity. Wetlands and water birds are interdependent, which emphasizes how delicate and complicated these ecosystems are. However, growing anthropogenic pressures such as habitat loss, pollution, climate change, and human disturbance are endangering water birds' ability to survive. The integrity of the entire wetland ecosystems that the water birds maintain is in danger, in addition to the birds themselves. As a result, conservation and management initiatives need to take an integrated approach that incorporates community involvement, strict monitoring, pollution prevention, habitat preservation, and climate adaptation. For these migratory and resident species to be protected, international collaboration is essential, as demonstrated by frameworks like the Ramsar Convention, migratory bird treaties, and regional conservation programs. The complex ecological roles of water birds, their reactions to new challenges, and creative conservation techniques should be the main topics of future studies. The only way we can guarantee the survival of water birds and the priceless wetland habitats they live in is by persistent scientific measures, policy changes and public commitment.

RESEARCH NEEDS

Even though the ecological importance of water birds in wetland ecosystems is becoming more widely acknowledged, there are still a number of unanswered questions regarding the complete spectrum of ecosystem services that these birds provide. Current understanding can be expanded upon in the following important areas by future research.

Quantification of ecosystem services

The services that water birds offer, including nutrient cycling, seed dissemination, pest control, and cultural values, are primarily qualitatively described in research. Quantitative evaluations of these services are urgently needed, nevertheless. Policymakers would be better able to incorporate avian contributions into wetland management and conservation planning if standardized methods for measuring and commercializing these services were developed.

Long-term and large-scale monitoring

In order to comprehend how the ecological services that water birds provide alter with climate, land-use change, and wetland degradation, longitudinal studies across several biogeographic zones are crucial. AI-driven picture analysis, citizen science, and satellite tracking might greatly improve data gathering and monitoring activities.

Role in climate change mitigation and adaptation

Priority should be given to studies on the ways in which water birds support climate resilience through their roles in wetland restoration, carbon sequestration (for example, through vegetation dynamics), and temperature adaptability. It is also crucial to look at how water bird populations and their ecological roles are impacted by climate change.

Interdisciplinary approaches

Working together, ornithologists, ecologists, economics, and social scientists can improve our comprehension of the functions of water birds. For example, combining contemporary scientific methods with local populations' traditional ecological knowledge (TEK) might result in comprehensive conservation plans.

Policy integration and conservation frameworks

Future research should concentrate on converting ecological discoveries into workable policies in order to close the gap between science and policy. This involves incorporating the environmental services provided by water birds into land-use planning, wetland valuation models, and international accords such as the Ramsar Convention.

Water bird-wetland interaction networks

Key species and interactions that preserve ecosystem stability and services can be identified by building intricate networks of interactions between water birds and other biotic elements (such as fish, invertebrates and plants). Keystone or umbrella species for conservation of prioritizing can also be found with the use of such networks.

Urban wetlands and novel ecosystems

Many wetlands are changing significantly as a result of growing development. How water birds are adjusting to these new ecosystems and whether they are still delivering vital ecosystem services in these changed settings should be the focus of future research.

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Integrating real-time soil sensor data with precision agriculture: A comprehensive approach to sustainable farming

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ABSTRACT

Precision agriculture, which relies on real-time data, is crucial for making farming more efficient and sustainable. This paper delves into an exciting area: how we can use real-time soil sensor data to make farming practices even better. We take a close look at the latest soil sensor technologies and how they can be integrated into precision agriculture systems. Soil sensors have come a long way, offering farmers detailed, up-to-the-minute information about their soil. In this review, we explore these technologies like electromagnetic induction, capacitance, and optical sensors, and discuss how they can be applied in precision agriculture. What makes this review stand out is that we dive deep into how using soil sensors alongside precision agriculture can benefit farming sustainability. We discuss how these sensors help in maintaining soil health, managing water efficiently, optimizing nutrient use, and overall, using resources wisely. Moreover, we evaluate how this integration can lead to more sustainable farming practices. We look at its impact on soil health, water conservation, nutrient management, and taking care of the environment. By bringing together recent research and practical examples, this review provides valuable insights for researchers, policymakers, and farmers alike. It emphasizes the importance of using data to make better decisions in agriculture, ultimately improving productivity while caring for the environment. In summary, this review sheds light on the exciting possibilities of integrating real-time soil sensor data with precision agriculture, offering practical guidance for creating a more sustainable future in farming.

Key words: Nutrient management, precision agriculture, real-time data, resource efficiency

INTRODUCTION

Precision agriculture has become a game-changer in modern farming, offering a way to boost efficiency and sustainability by using real-time data (Smith et al., 2023). A key component of precision agriculture is the use of soil sensor technologies, which give farmers valuable insights into soil conditions (Jones and Smith, 2022). This paper explores how integrating real-time soil sensor data with precision agriculture techniques can lead to more sustainable farming practices. By bringing together soil sensors and precision agriculture, farmers can make smarter decisions about how they manage their land. Soil sensors provide information like moisture levels, nutrient content, pH, temperature, and salinity in real-time, helping farmers understand what's happening beneath the soil. The importance of this paper is clear: it's about finding ways to make farming smarter and more sustainable. When farmers have access to real-time soil data, they can fine-tune their actions to be more precise and efficient. For example, knowing exactly how much moisture is in the soil helps farmers schedule irrigation more effectively, avoiding both water waste and crop stress during droughts (Wang et al., 2021). Similarly, monitoring nutrient levels allows farmers to apply fertilizers only where and when they're needed, reducing waste and environmental harm (Brown and White, 2020). This work is significant because it offers a pathway to revolutionize farming towards sustainability. Sustainable farming is all about meeting today's needs without compromising the ability of future generations to meet theirs. By integrating soil sensor data with precision agriculture, we can move closer to achieving this balance. Moreover, with challenges like climate change, soil degradation, and water scarcity, sustainable practices are more critical than ever. Soil sensors can help farmers tackle these challenges by promoting efficient resource use, improving soil health, and reducing environmental impacts. In summary, this paper aims to explore how combining real-time soil sensor data with precision agriculture can transform farming practices, making them more sustainable and resilient in the face of modern challenges.

SOIL SENSOR TECHNOLOGIES

Recent advancements in soil sensor technologies have revolutionized the way soil parameters are monitored. Soil sensors can provide real-time data on various soil properties including moisture content, nutrient levels, pH, temperature, and salinity. Advanced sensors utilize techniques such as electromagnetic induction, capacitance, and optical sensors to measure soil parameters accurately and efficiently. Some of the advanced techniques used in these sensors are enlisted below:

Electromagnetic induction sensors

These sensors measure the electrical conductivity of the soil, which correlates with various soil properties such as moisture content and salinity. Electromagnetic induction sensors are particularly useful for mapping soil variability across large fields, providing farmers with detailed insights into the spatial variability of soil properties (Doolittle and Brevik, 2014).

Capacitance sensors

These sensors measure the soil's ability to hold an electrical charge, which is directly related to soil moisture content. Capacitance sensors are highly sensitive and can provide continuous, real-time data, making them ideal for precise irrigation management (Kizito et al., 2008).

Optical sensors

Utilizing light reflectance and fluorescence, optical sensors can determine soil properties such as organic matter content and nutrient levels. These sensors are often used in conjunction with other technologies, like drones or satellite imagery, to provide comprehensive soil health assessments (Ng et al., 2019).

APPLICATIONS OF SOIL SENSORS IN PRECISION AGRICULTURE

Real-time soil sensor data finds applications in various aspects of precision agriculture:

Soil moisture monitoring

Soil moisture monitoring is a cornerstone of precision agriculture, providing critical information that helps farmers manage water resources more effectively. Real-time soil moisture data enables farmers to make informed decisions about irrigation scheduling, ensuring that crops receive the optimal amount of water at the right times. This practice not only enhances crop health and yield but also conserves water, a valuable and often limited resource.

Water is essential for plant growth, influencing everything from seed germination to nutrient uptake and overall plant health. Proper irrigation is crucial to avoid two major issues: waterlogging and drought stress. Waterlogging occurs when soil is oversaturated, leading to reduced oxygen availability and root damage. On the other hand, drought stress happens when there is insufficient water, causing plants to wilt and reducing photosynthesis. Both conditions can severely impact crop yield and quality (Wang et al., 2021).

Real-time soil moisture sensors provide continuous data on the water content in the soil, allowing farmers to adjust irrigation practices dynamically. This helps maintain soil moisture at levels that are ideal for crop growth, reducing the risks associated with both under- and over-watering.

Technologies and methods

Modern soil moisture sensors use various technologies to measure water content accurately:

Capacitance sensors

These sensors measure the dielectric constant of the soil, which changes with moisture content. They are known for their sensitivity and accuracy, providing reliable data for precise irrigation management (Kizito et al., 2008).

Time Domain Reflectometry (TDR) sensors

TDR sensors measure the time it takes for an electromagnetic pulse to travel through the soil. This travel time varies with the soil's moisture content, allowing for accurate moisture measurement (Robinson et al., 2003).

Neutron probe

This method involves measuring the scattering of neutrons in the soil, which correlates with soil moisture. While highly accurate, neutron probes are more complex and expensive, often used in research rather than everyday farming (Evett, 2003).

Practical applications and benefits

One practical example of the impact soil moisture monitoring comes from California, where farmers have used soil moisture sensors to optimize their irrigation schedules. By continuously monitoring soil moisture levels, they adjusted the timing and amount of water applied to their crops. This approach led to a remarkable 20% reduction in water usage while maintaining, or even improving, crop yields (Johnson et al., 2023).

This example highlights several key benefits of soil moisture monitoring:

Water conservation

With accurate soil moisture data, farmers can reduce water waste, a critical benefit in regions facing water scarcity or drought conditions.

Cost savings

Efficient water use translates to lower irrigation costs, saving money on water and energy used for pumping.

Improved crop health

Maintaining optimal soil moisture levels helps prevent stress on plants, leading to healthier crops and higher yields.

Environmental protection

Reducing water usage helps conserve local water resources and prevents issues like soil erosion and nutrient runoff.

Future strategies

The future of soil moisture monitoring in precision agriculture looks promising, with ongoing advancements aimed at improving accuracy, affordability, and ease of use. Emerging technologies, such as wireless sensor networks and IoT, are expected to enhance real-time monitoring capabilities, allowing for more seamless data integration and management (Rodrigues et al., 2018).

Additionally, machine learning and data analytics are increasingly being used to interpret soil moisture data, providing predictive insights and automated irrigation recommendations. These innovations will further refine irrigation practices, making precision agriculture even more effective and sustainable (Shamshiri et al., 2018).

Fig. 1 (a & b) presents a conceptual framework for integrating real-time soil sensor data with precision agriculture systems which consists of two stages: (a) data collection, pre-processing, and model training using real-time soil sensor inputs, and (b) testing trained models with new field data to support decision-making and the implementation of control hardware such as automated irrigation and fertilization systems. This model-driven approach demonstrates how soil moisture data can be transformed into actionable management decisions, supporting efficient resource use and sustainable farming practices (Elashmawy and Ismail, 2023).

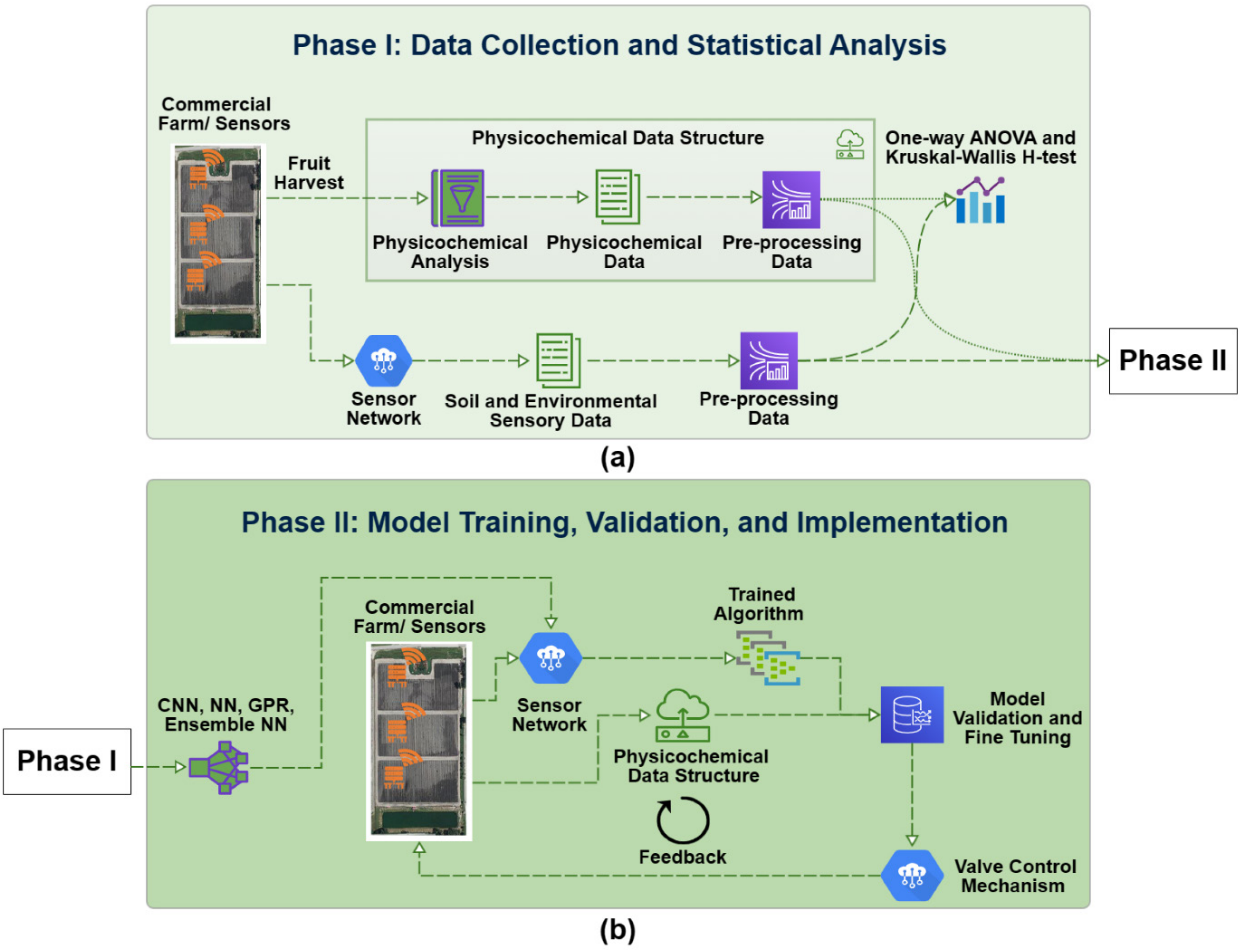

Fig. 1 (a & b). Two stages of framework for integrating real-time soil sensor data

Nutrient management

Soil sensors have become a game-changer in nutrient management, allowing farmers to precisely monitor nutrient levels in their fields. This precision enables tailored fertilization strategies, which are crucial for optimizing plant growth while minimizing environmental impact. By using real-time data from soil sensors, farmers can apply fertilizers more efficiently, ensuring that plants get the nutrients they need at the right time and in the right amounts (Brown and White, 2020). For instance, soil sensors can measure the levels of essential nutrients like nitrogen, phosphorus, and potassium. This real-time information helps farmers decide when and where to apply fertilizers, avoiding the traditional one-size-fits-all approach. Tailored fertilization not only enhances crop yields but also reduces the risk of nutrient runoff into nearby water bodies, which can cause significant environmental issues like algal blooms and water pollution.

Studies have highlighted the effectiveness of this approach. For example, research has shown that precision nutrient management based on soil sensor data can reduce nitrogen leaching by up to 50% compared to conventional fertilization practices (Smith et al., 2022). This reduction is significant, as nitrogen leaching into groundwater and surface water can lead to serious ecological problems, including the contamination of drinking water sources and the disruption of aquatic ecosystems. The practical benefits of soil sensor technology in nutrient management are evident in real-world applications. For example, in Iowa, farmers using soil sensors to guide their fertilization practices have reported improved crop performance and reduced fertilizer costs. This approach not only helps in maintaining soil health but also supports the long-term sustainability of farming operations by preventing the over-application of fertilizers, which can degrade soil quality over time. Moreover, integrating soil sensors with other technologies, such as GPS and data analytics platforms, allows for even more precise nutrient management. Farmers can create detailed maps of nutrient variability across their fields, enabling them to apply fertilizers more accurately and efficiently. This integration also supports the development of variable rate technology (VRT), which adjusts the application rates of fertilizers in real time based on soil sensor data. In summary, the use of soil sensors in nutrient management represents a significant advancement in precision agriculture. By enabling precise monitoring and tailored fertilization strategies, these sensors help farmers improve crop yields, reduce costs, and minimize environmental impacts. This technology not only enhances the efficiency of nutrient use but also promotes sustainable farming practices that are vital for the future of agriculture.

IMPACT ON SOIL HEALTH AND FERTILITY

The integration of soil sensor data into precision agriculture has significant positive impacts on soil health and fertility. This advanced technology supports sustainable farming practices by optimizing the use of inputs and enhancing soil structure, all while minimizing environmental impacts.

Preventing overuse of inputs

One of the primary benefits of using soil sensors is the ability to prevent the overuse of water and fertilizers. By providing real-time data on soil moisture and nutrient levels, soil sensors enable farmers to apply these inputs precisely where and when they are needed, avoiding excess. This precision reduces the risk of soil degradation and nutrient imbalances, which can occur when inputs are applied uniformly without regard to the specific needs of different areas of a field (Garcia et al., 2023).

For example, a study found that farmers who used soil sensors were able to reduce their fertilizer application rates by 15%. This reduction not only led to cost savings but also improved soil health by preventing the accumulation of excess nutrients that can harm soil microorganisms and plant roots (Chen et al., 2023). Additionally, less nutrient runoff into water bodies was observed, highlighting the environmental benefits of this approach.

Enhancing soil structure

Proper moisture management, facilitated by soil sensors, plays a crucial role in maintaining and improving soil structure. By ensuring that soil moisture levels are kept within optimal ranges, soil sensors help prevent conditions that lead to soil compaction and erosion. Compacted soil can restrict root growth and reduce the soil's ability to retain water and nutrients, while erosion can lead to the loss of topsoil and essential nutrients (Lee and Kim, 2021).

For instance, real-time soil moisture monitoring can help maintain the right balance of water in the soil, which is essential for healthy soil structure. This balance prevents the soil from becoming too dry and prone to wind erosion or too wet and susceptible to water erosion. Improved soil structure enhances water infiltration rates, ensuring that more water reaches plant roots rather than running off the surface (Zhang et al., 2020).

Minimizing environmental impact

The precise application of nutrients and water not only benefits soil health but also has significant environmental advantages. By reducing the leaching of nutrients and agrochemicals into the surrounding environment, soil sensors help minimize pollution and protect local ecosystems. Excessive leaching can lead to the contamination of groundwater and surface water, harming aquatic life and posing risks to human health.

For example, the use of real-time soil moisture sensors to maintain optimal soil moisture levels has been shown to improve soil structure and increase water infiltration rates. This results in less runoff and lower levels of nutrient and chemical leaching into water bodies (Zhang et al., 2020). Consequently, the environmental footprint of farming operations is reduced, contributing to the overall sustainability of agricultural practices.

In summary, integrating soil sensor data into precision agriculture significantly enhances soil health and fertility by preventing the overuse of inputs, improving soil structure, and minimizing environmental impacts. These advancements support sustainable farming practices, ensuring that agriculture can continue to meet the needs of the present without compromising the ability of future generations to meet their own needs.

WATER MANAGEMENT AND CONSERVATION

Effective water management is a critical component of sustainable farming, and real-time soil moisture data plays a pivotal role in this process. By providing precise information about soil moisture levels, soil sensors enable farmers to optimize irrigation practices, conserve water, and mitigate the effects of drought.

Optimizing irrigation

One of the most significant benefits of real-time soil moisture data is its ability to optimize irrigation. Soil sensors help farmers determine exactly when and how much water to apply, reducing both water waste and energy consumption associated with irrigation. This precision is particularly beneficial in areas where water resources are scarce or where water costs are high.

For instance, vineyards that adopted soil moisture-based irrigation scheduling experienced impressive results. By adjusting their irrigation practices according to real-time soil moisture data, these vineyards achieved a 30% reduction in water usage. This significant saving was accomplished without sacrificing crop yields; in fact, some vineyards saw increased productivity due to more efficient water use (Gonzalez et al., 2023). This example highlights how precision irrigation can lead to substantial water conservation and cost savings, making it an essential practice for sustainable agriculture.

Drought mitigation

In addition to optimizing irrigation, real-time soil moisture monitoring is crucial for drought mitigation. Soil sensors provide real time detection of soil moisture deficits, allowing farmers to implement timely irrigation and other drought mitigation strategies before crops suffer severe water stress (Li et al., 2024). This proactive approach helps to maintain crop health and yield, even during extended dry periods.

For example, in drought-prone regions, farmers using soil moisture sensors were able to respond quickly to early signs of soil moisture deficits. By implementing timely irrigation based on sensor data, these farmers significantly mitigated yield losses during dry spells (Wu et al., 2022). This capability is particularly important as climate change increases the frequency and severity of droughts, posing greater challenges to agricultural productivity.

Overall, the use of real-time soil moisture data for water management and conservation demonstrates a powerful tool for enhancing agricultural sustainability. By optimizing irrigation and enabling effective drought mitigation, soil sensors help farmers use water resources more efficiently, reduce environmental impact, and ensure the long-term viability of their farming operations.

NUTRIENT OPTIMIZATION

Precision nutrient management, guided by real-time soil sensor data, significantly enhances nutrient use efficiency and reduces environmental impacts. This approach allows farmers to apply fertilizers more accurately, ensuring that crops receive the right amount of nutrients at the right time, leading to numerous benefits.

Improved nutrient use efficiency

One of the key advantages of using soil sensors for nutrient management is the improvement in nutrient use efficiency. By applying fertilizers based on the actual nutrient levels detected in the soil, farmers can minimize wastage and ensure that plants get the nutrients they need without excess. This precision reduces the environmental pollution typically associated with over-fertilization, such as nitrogen leaching into groundwater and runoff into surface waters (Malik et al., 2023).

For instance, farms that implemented variable-rate nutrient application based on soil sensor data achieved a 15% higher nitrogen use efficiency compared to those using uniform application methods (Brown et al., 2021). This increase in efficiency not only reduces fertilizer costs but also enhances crop growth and yield, as plants can better utilize the available nutrients. This example illustrates how precision nutrient management can make farming more sustainable and economically viable.

Reduced nutrient runoff

Another significant benefit of precision nutrient management is the reduction in nutrient runoff. By avoiding the over-application of fertilizers, the risk of excess nutrients washing into nearby water bodies is minimized. This practice helps protect water quality by reducing the likelihood of nutrient pollution, which can lead to problems such as algal blooms and the degradation of aquatic ecosystems (Zhang and Wang, 2023).

For example, farms utilizing precision nutrient management techniques reported a 40% reduction in phosphorus runoff, contributing to improved water quality in adjacent waterways (Gao et al., 2022). This reduction in runoff not only helps maintain the health of local water bodies but also ensures that more of the applied nutrients remain in the soil where they can benefit crops.

By integrating real-time soil sensor data into nutrient management strategies, farmers can optimize their use of fertilizers, enhance crop productivity, and minimize environmental impacts. Improved nutrient use efficiency means that crops receive just the right amount of nutrients, leading to better growth and higher yields without the excessive use of fertilizers. Meanwhile, reducing nutrient runoff helps protect surrounding ecosystems and water resources, contributing to a more sustainable agricultural practice overall. In summary, precision nutrient management based on soil sensor data represents a significant advancement in farming technology. It allows for more efficient use of fertilizers, reducing waste and environmental harm, and promoting sustainable agricultural practices that benefit both the farmer and the environment.

SUSTAINABILITY IMPLICATIONS

The integration of soil sensors with precision agriculture practices plays a vital role in promoting sustainability within farming systems. By enhancing resource use efficiency and protecting the environment, these advanced technologies help create more resilient and sustainable agricultural practices.

Resource use efficiency

One of the primary benefits of integrating soil sensors with precision agriculture is the optimization of resource use. By providing real-time data on soil moisture, nutrient levels, and other critical parameters, soil sensors enable farmers to apply inputs such as water, fertilizers, and energy more precisely. This precision helps reduce waste, lower costs, and improve the overall efficiency of farming operations (Snyder et al., 2023).

For example, farms that adopted precision agriculture practices with soil sensors reported using 25% less water and 20% less fertilizer while maintaining or even increasing their crop yields (Martinez et al., 2021). These savings are significant, particularly in regions where water scarcity and high input costs are major concerns. By using resources more efficiently, farmers can reduce their environmental footprint and enhance the sustainability of their operations.

Environmental protection

In addition to improving resource use efficiency, the integration of soil sensors with precision agriculture contributes significantly to environmental protection. By minimizing nutrient runoff, reducing the use of agrochemicals, and preserving soil health, these practices help mitigate the environmental impacts of farming (Li and Zhang, 2023). For instance, the adoption of precision agriculture techniques has been shown to reduce pesticide use by 30%, leading to decreased environmental contamination (Wu and Liu, 2023). This reduction in chemical usage not only benefits the surrounding ecosystems by reducing the risk of pollution but also helps maintain biodiversity and improve the overall health of the environment. Furthermore, by preventing nutrient runoff into water bodies, precision agriculture helps protect water quality and reduces the occurrence of harmful algal blooms and other forms of water pollution.

The sustainability implications of integrating soil sensors with precision agriculture are profound. By optimizing the use of inputs and protecting the environment, these technologies support the development of farming systems that are both productive and sustainable. Improved resource use efficiency translates to lower input costs and higher profitability for farmers, while environmental protection measures help ensure that agricultural practices do not harm the surrounding ecosystems.In summary, the integration of soil sensors with precision agriculture is a key driver of sustainable farming practices. It enables more efficient use of water, fertilizers, and energy, reduces the environmental impact of farming, and helps maintain soil health. These advancements not only benefit farmers by improving the efficiency and profitability of their operations but also contribute to the broader goal of achieving sustainable agriculture that can support future generations.

CHALLENGES AND FUTURE STRATEGY

While the integration of soil sensors with precision agriculture offers numerous benefits, there are also several challenges that need to be addressed to fully realize its potential. These challenges include cost and accessibility, data interpretation, integration with existing farm management systems, and ongoing research needs.

Cost and accessibility

One of the primary challenges associated with soil sensor technology is the initial investment required for purchase and installation. High-quality soil sensors and the associated infrastructure can be expensive, making it difficult for small-scale farmers or those in developing regions to adopt these technologies (Roberts and Johnson, 2024). Additionally, accessibility to these advanced tools can be limited by geographical and economic factors, further widening the gap between technologically advanced and resource-constrained farming operations.

To overcome these barriers, there is a need for initiatives that can subsidize the cost of soil sensors, provide financial support or incentives to farmers, and promote the development of affordable sensor technologies. Collaborative efforts between governments, research institutions, and private companies can help make these technologies more accessible to a broader range of farmers, ensuring that the benefits of precision agriculture are widely shared.

Data interpretation

Another significant challenge lies in the proper interpretation of soil sensor data. While these sensors can provide a wealth of real-time information, translating this data into actionable insights requires expertise in data analysis and an understanding of soil science (Gomez and Rodriguez, 2023). Farmers may find it difficult to interpret the complex data and make informed decisions without adequate training or support.

To address this issue, user-friendly interfaces and decision-support systems need to be developed, enabling farmers to easily understand and act on the data provided by soil sensors. Training programs and extension services can also play a crucial role in educating farmers on how to effectively use sensor data to optimize their farming practices.

Integration with farm management systems

Seamless integration of soil sensor data with existing farm management systems is crucial for maximizing the benefits of precision agriculture. However, many farms face challenges in integrating new technologies with their current systems, which may not be designed to handle the influx of real-time data from sensors (Huang et al., 2022). Compatibility issues and the need for significant modifications to existing infrastructure can pose substantial barriers. To facilitate integration, software developers and agricultural technology companies must work towards creating interoperable systems that can easily incorporate sensor data. This includes developing standardized protocols and platforms that allow for smooth data transfer and synchronization between different technologies and management systems.

Research needs

Further research is essential to improve the accuracy, calibration, and long-term impact of soil sensors on soil health. While current sensors offer valuable data, there is always room for improvement in their precision and reliability (Xu et al., 2024). Additionally, understanding the long-term effects of continuous monitoring and precise input application on soil health and ecosystem balance is crucial for sustainable agriculture.'

Research efforts should focus on advancing sensor technology, refining calibration techniques, and conducting longitudinal studies to assess the impacts of precision agriculture on soil health. Collaboration between academic institutions, government agencies, and the private sector can drive innovation and ensure that the latest findings are translated into practical solutions for farmers.

Addressing these challenges is critical for the widespread adoption and success of soil sensors in precision agriculture. By overcoming barriers related to cost, accessibility, data interpretation, and integration, and by investing in ongoing research, we can ensure that these advanced technologies are used effectively to promote sustainable farming practices. The continued development and refinement of soil sensor technology will play a key role in shaping the future of agriculture, making it more efficient, productive, and environmentally friendly.

The integration of real-time soil sensor data with precision agriculture represents a pivotal advancement towards achieving sustainable farming practices. By harnessing the power of advanced technology, farmers can optimize resource use, enhance soil health, and minimize environmental impacts, thereby ensuring the long-term viability of agricultural systems. Precision agriculture, guided by soil sensor data, allows farmers to make informed decisions based on real-time information about soil moisture, nutrient levels, and other crucial parameters. This capability leads to more efficient use of water, fertilizers, and energy, reducing waste and costs while maximizing crop yields. Studies have shown that farms adopting precision agriculture techniques with soil sensors achieve significant reductions in water and fertilizer use, often while increasing productivity. Moreover, the integration of soil sensors supports sustainable soil management practices by preventing overuse of inputs and promoting soil health. By avoiding excessive fertilization and ensuring optimal soil moisture levels, farmers can minimize soil degradation, erosion, and nutrient runoff into water bodies. This not only preserves the productivity of agricultural land but also safeguards water quality and biodiversity.

However, challenges such as the initial costs of technology, data interpretation complexities, and the integration of sensor data with existing farm management systems need to be addressed for widespread adoption. Investments in research and development are crucial to improving sensor accuracy, calibration methods, and long-term impacts on soil ecosystems (Xu et al., 2024). Moreover, efforts to enhance accessibility and provide adequate training and support for farmers will be key in overcoming these challenges.

Thus, the integration of real-time soil sensor data with precision agriculture offers a pathway towards sustainable agriculture that balances productivity with environmental stewardship. By continually advancing technology, fostering collaboration, and supporting informed decision-making, we can ensure that agriculture meets the needs of today without compromising the ability of future generations to meet their own needs. Embracing these innovations is not just beneficial but essential for creating a resilient and sustainable food system for a growing global population.

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Yield assessment of sweet corn cv. Sugar-75 in coastal agro-ecosystem of Odisha, India

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ABSTRACT

Front line demonstration of sweet corn cv. Sugar-75 was conducted at Gokarnapur village of Digapahandi block of Ganjam district to assess its productivity in coastal plain zone of Odisha. The study comprised of 10 farmers in cluster approach during *kharif* 2023 and 2024 was undertaken by Krishi Vigyan Kendra, Ganjam-II, Berhampur, Odisha. Observation on growth and yield parameters were recorded, and economic analysis was done. The final seed yield was recorded after harvest, and the gross return was calculated based on the prevailing market price.The results from the study conclusively proved that demonstration of the sweet corn variety Sugar 75 recorded higher green cob yield 144.0 q ha^1 as compared to farmers practice of normal maize 42.5 q ha^{-1}. The enhancement in the demonstration yield over farmer's practices turned into 238%. By conducting front-line demonstrations on sweet corn in large scale in farmers field will increase the income level of farmers and improve the livelihood condition of the farming community.

Key words: Early-maturing, hybrid, resilient, sweet corn

INTRODUCTION

Sweet corn *(Zea mays* var. *saccharata)* is a highly valued crop due to its sweet taste and good source of vitamin C and A. The variety produces uniform, medium-to-large cobs with bright golden-yellow kernels that are tender, sugary, and retain sweetness for a longer duration after harvest. It is suitable for cultivation under diverse agro-climatic conditions, showing good tolerance to major pests and diseases. With a yield potential of 17-20 t ha^{-1}, Sugar-75 has emerged as a profitable crop for farmers, especially in peri-urban and commercial farming systems. Harvested green stalks are highly succulent, palatable and digestible for feeding. Hence, it is called as king of fodder. Its increasing demand in fresh markets, food processing, and export makes Sugar-75 an ideal variety to ensure both nutritional security and enhanced farm income (Singh et al., 2020).

Keeping its popularity, authors studied the performance of high-yielding sweet corn cv. Sugar-75 incomparison to local maize, focusing on yield attributes, profitability and consumer acceptability through front line demonstration in the existing farming situation for substitution of local maize.

MATERIALS AND METHODS

The study was conducted through front line demonstration during the *kharif* seasons of 2023 and 2024 in Gokarnapur village of Digapahandi block of Ganjam district in the east and southeastern coastal plain of Odisha state with an objective to evaluate the performance of the sweetcorn cv. Sugar-75. The experimental site was situated at 19° 37' 15.158" N latitude and 84° 57' 25.234"E longitude, with an average elevation of 26m above sea level. The region experiences a specific climate, with average rainfall of 1276.2 mm during the study period (June to September). The mean maximum and minimum temperatures observed were 39°C and 18.9°C, respectively. The soil of the experimental site is slightly acidic in reaction (pH: 5.6), sandy loam texture with organic carbon content 0.48%, low in nitrogen 135.5 kg ha^{-1}, low in phosphorus 15.1 kg ha^{-1} and medium in potassium 168.4 kg ha^{-1} contents. The observations were recorded from demonstration plots and farmers' field, covering growth and yield parameters such as plant height, no. of cobs per plant, cob length (cm), green cob yield (q ha^{-1}), and grain yield at maturity stage and the gross returns (Rs ha^{-1}) were calculated based on the prevailing market prices of the produce. Similar methods were also undertaken earlier by Shah et al., 2013 and Bijlwan et al., 2020. Harvest index is the relationship between economic yield and biological yield. It was calculated by using the following formula.

$$\text{Harvest Index}(\%) = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

RESULTS AND DISCUSSION

Front line demonstrations were taken up to assess the yield potential in the farmers' fields. Under the study, both normal maize and Sugar-75 varieties were taken in adjacent plots of the village. Local maize was demonstrated with traditional cultivation practices e.g. more seed rate (15 kg ha^{-1}), no seed treatment, broadcasting, manual weeding at 45 DAS with improper fertilizer application per ha where as in the demonstrated technologies, besides hybrid sweet corn Sugar - 75, other important cultivation practices like proper seed rate, seed treatment with *Trichoderma viride* and *Pseudomonas fluorescens,* line sowing, proper fertilizer and weed managements were taken as indicated in Table 1.

Table 1. Comparison between farmers' practice and demonstrated technologies

Sl. No.	Particulars	Farmers practice	Tested technology
1	Variety	Normal grain maize (starchy, used for grain purpose)	Sweet corn hybrid Sugar-75 (grown for tender, sweet cobs)
2	Seed rate	25 kg ha^{-1}	Recommended (10-12 kg ha^{-1})
3	Seed treatment	No seed treatment	*Trichoderma viride* @ 4 g kg^{-1} seed and *Pseudomonas fluorescens* @ 10 g kg^{-1} seed
4	Method of sowing	No proper spacing	Row-to-row: 60-75 cm, Plant-to-plant: 20-25 cm
5	Fertilizer application	Unbalanced dose of fertilizer	NPK (120: 60: 40 kg ha^{-1}) 0.5 % $ZnSO_4$ sprayed 2-3 times at 15 days interval and 0.2 % Borax solution sprayed at tasselling and silking stage
6	Weed management	Manual weeding at 40- 50 DAS	Pre-emergence application of Atrazine 1.0-1.5 kg a.i. ha^{-1} at 2 DAS and post emergence application of Tembotrione 120 g a. i.ha^{-1} at 20 DAS

The major differences between the demonstrated package and farmers' practice were observed as recommended varieties, seed treatment, soil test-based fertilizer application and weeding. Similar procedures were also followed by Banotra et al., 2017 and Lone et al., 2022. These are the primary cultivation practices for any field crop to get higher yield. Fig.1 indicates the higher yield potential of the demonstrated practice.

Fig. 1. Taking observation on number of grains per cob

Table 2. Effect of different treatments on growth and yield parameters (1st Year)

Treatments	Plant height (cm)	No. of cobs/ plant	No. of grains/ cob	Weight of cob (g)	Green cob yield (q ha^{-1})	Grain yield (q ha^{-1})
Farmer's practice (Common maize)	132.8	1.14	229.5	141.6	40.4	28.5
Improved practice (Sweet corn cv. Sugar 75)	143.4	1.71	424.6	274.3	136.8	44.0

Table 3. Effect of different treatments on growth and yield parameters (2nd Year)

Treatments	Plant height (cm)	No. of cobs/ plant	No. of grains/ cob	Weight of cob (g)	Green cob yield (q ha^{-1})	Grain yield (q ha^{-1})
Farmer's practice (Common maize)	146.8	1.26	253.7	156.6	44.6	31.5
Improved practice (Sweet corn cv. Sugar 75)	158.4	1.89	469.2	303.1	151.2	48.6

Table 4. Effect of different treatments on growth and yield parameters (Pooled data of 2 years)

Treatments	Plant height (cm)	No. of cobs/ plant	No. of grains/ cob	Weight of cob (g)	Green cob yield (q ha^{-1})	Grain yield (q ha^{-1})
Farmer's practice (Common maize)	139.8	1.20	241.6	149.1	42.5	30.0
Improved practice (Sweet corn cv. Sugar 75)	150.9	1.80	446.9	288.7	144.0	46.3

Table 2-4 revealed the differences in growth and yield attributes of maize under different management practices during both years of experimentation. The improved practice (Sweet corn cv. Sugar 75) recorded the highest plant height (150.9 cm), number of cobs per plant (1.80), number of grains per cob (446.9), cob weight (288.7 g), green cob yield (144.0 q ha^{-1}), and grain yield (46.3 q ha^{-1}), which were markedly superior to the farmer's practice (common maize). It corroborates with the findings of Jayesh et al., 2020 and Charan et al., 2010. Fig. 2 shows the higher productivity in the demonstrated variety than the local one.

Fig. 2. Harvesting from the demonstration plot

Table 5. Economics of the assessed varieties (Average pooled data over 2 years)

Treatments	Cost of cultivation (Rs ha^{-1})	Gross return (Rs ha^{-1})	Net return (Rs ha^{-1})	B: C	Harvest index
Farmer's practice (Local maize)	32000	91200	59200	2.8	38.7%
Improved practice (Sweet corn cv. Sugar 75)	52000	175000	123000	3.3	44.5%

Table 5 reveals the economics of both the technologies tested in farmer's field. Sweet corn generated much higher gross returns (Rs 1,75,000 ha^{-1}) than local maize (Rs. 91,200 ha^{-1}) due to higher yield and market price. Sweet corn yielded a net return of Rs. 1,23,000 ha^{-1} nearly double that of local maize (Rs.59,200 ha^{-1}). Similar economic benifits have also been reported by Mahajan et al., 2017 and Khan et al., 2009. The BC ratio in the local cultivation practices was only 2.8. A higher harvest index (44.5%) in sweet corn suggests better partitioning of dry matter into economic yield compared to local maize (38.7%). It corroborates the findings of Bhadu et al., 2017.

CONCLUSION

The demonstration of sweet corn cv. Sugar-75 clearly established its superiority over local maize. While normal maize requires a longer duration, produces mainly starchy grains with low market demand, and gives comparatively low returns, Sugar-75 proved to be an early-maturing (75-80 days), high-yielding (14-15 t ha^{-1}green cobs), and nutritionally superior variety. Its tender, golden-yellow, sugary kernels are highly preferred in urban fresh markets and by food processing industries, fetching a premium price compared to normal maize. Farmers also benefit from higher fodder yield and assured marketability.Thus, the adoption of Sugar-75 not only ensures better profitability and quicker returns but also contributes to nutritional security and diversification of maize-based farming systems.

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Advancing sustainable agriculture through CRISPR/Cas-mediated crop improvement

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ABSTRACT

CRISPR/Cas is a precise and efficient genome-editing technology that has revolutionized crop improvement by enabling the development of crops that are more productive, resilient, and nutritionally enhanced. As global agriculture faces pressures from climate change, pests, diseases, land degradation, and rising food demand, CRISPR/Cas-based approaches offer unprecedented opportunities for building a sustainable and resilient food system. Compared to traditional breeding and earlier genetic modification techniques, CRISPR/Cas is faster, highly accurate, and capable of achieving desired traits in less time. It enhances crop resistance to both abiotic and biotic stresses, improves nutrient uptake, mitigates the effects of heavy metals, and supports plant growth under challenging conditions such as drought, salinity, and heat. Beyond stress resilience, CRISPR/Cas is being used to improve nutritional quality, including iron and zinc-enriched grains, low-gluten wheat for celiac-sensitive individuals, and oilseeds with healthier fatty acid profiles. These improvements not only benefit farmers and consumers but also reduce the environmental footprint of agriculture by decreasing the need for fertilizers, pesticides, and irrigation, thereby conserving water and lowering carbon emissions. Despite these advantages, several challenges remain, including potential off-target genetic edits, difficulties in delivering CRISPR components to certain species, and varying ethical and regulatory frameworks across countries. Addressing these issues requires transparent communication, public engagement, and inclusive policies to ensure equitable access, particularly for smallholder farmers and developing regions. The future of CRISPR/Cas is further strengthened by integration with emerging technologies such as artificial intelligence, machine learning, and speed breeding. Together, these innovations herald a new era of sustainable agriculture and serve as a cornerstone for global food security, enabling the development of high-yielding, climate-resilient, and nutrient-rich varieties that contribute to multiple Sustainable Development Goals (SDGs).

Key words: Artificial intelligence, CRISPR, crop improvement, gene editing, genomics

INTRODUCTION

A potent molecular tool for many biological research fields where it is helpful to target or alter particular DNA sequences is the clustered regularly interspaced short palindromic repeats (CRISPR)-Cas9 genome engineering technology (Hsu et al., 2014; Sander and Joung, 2014; Cox et al., 2015; Wright et al., 2016). The Cas9 nuclease, which was initially developed from the CRISPR-Cas bacterial adaptive immune system (Barrangou et al., 2007), can locate and cleave a target DNA using a guide RNA (Gasiunas et al*.,* 2012). In eukaryotic cells, the Cas9 nuclease has been designed to modify target DNA at specific locations (Mali et al*.,* 2013). However like its predecessors in genome editing, zinc finger nucleases and transcriptional activator-like effector nucleases, Cas9 is known to bind and cleave at off-target sites in the context of large eukaryotic genomes (Fu et al*.,* 2013). Therefore, there has been a lot of interest in the field in efforts to quantify, comprehend, and enhance Cas9 specificity. Although earlier review articles should be consulted for background information and understanding of the development and applications of Cas9 genome editing but in last five years, novel mutant lines with improved desirable traits have been produced in large part by CRISPR-based genome-editing techniques for crop genome modification. The ability to simultaneously improve multiple traits directly in elite lines is one of the biggest benefits of using genome editing techniques for crop breeding. This option speeds up the development of commercial products, which is typically impractical when using conventional breeding (Gao et al*.,* 2020). These strategies, commonly known as multiplex editing, involve the simultaneous modification of several loci, which is particularly important for the improvement of characteristics controlled by QTLs (Quantitative Trait Loci) (Rodríguez-Leal et al*.,* 2017). Therefore, the CRISPR system has been a significant advancement in genome editing technology, particularly as it confers target specificity without relying on the drawn-out and expensive process of protein modification. The technology swiftly spread throughout labs worldwide since, generally speaking, reprogramming the system to edit other targets hinges merely on the exchange of guide RNA molecules. Since then, a number of organisms and crop plants have benefited from the increased efficiency of CRISPR/Cas genome editing technology (Li et al., 2020).

CRISPR - A REVOLUTION IN GENOME EDITING

The story of CRISPR begins with a bacterium. Japanese researchers who looked into the genome of the bacterium *E. coli* announced the first finding of CRISPR sequences in 1987. They discovered five identical DNA fragments that were repeated and divided by identically sized non-repetitive DNA sequences. Since these DNA repetitions could not be explained at the time, they were regarded as a curiosity. Nevertheless, these repetitive DNA sequences were consistently observed by researchers looking at the genomes of additional bacterial species. These species included gut-dwelling bacteria and those utilized to produce cheese and yoghurt. Since then, it has been discovered that CRISPR sequences are present in over half of all bacterial species (Makarova et al., 2015). The puzzle was further compounded by the discovery that these regular DNA repetitions usually co-occur with a common set of genes known as CAS genes. A group of Dutch microbiologists named the DNA region containing these repeats "CRISPR" in 2002. "CRISPR" stands for "clustered regularly interspaced short palindromic repeats," and the associated genes were dubbed "CAS" genes, or CRISPR-associated genes (Jansen et al*.,* 2002). The proteins that the CAS genes encode act as molecular scissors that can cut DNA, as was soon discovered. The DNA sequences between the repeats are nearly identical to the genetic material of viruses that infect bacteria (Mojica et al., 2005; Pourcel et al*.,* 2005). The idea that CRISPR-Cas was a mechanism to defend bacteria against bacteriophages was then put forth. The bacterium employs Cas proteins in conjunction with DNA sequences it has collected from invasive viruses to identify and cut the attacking viruses' DNA. Researchers initially experimentally showed that CRISPR-Cas is an efficient component of the bacterial immune system in 2007 using the yogurt-making bacterium *Streptococcus thermophilus*. Bacteria that are repeatedly exposed to a virus eventually become resistant to it. The presence of viral DNA pieces in the bacteria's CRISPR region coexists with this resistance. The resistance vanished right away once the researchers extracted the viral segments from the CRISPR area. Over time, other CRISPR-Cas systems have been discovered, and while they differ in certain ways, the process is always the same. The bacterium's CRISPR library contains DNA fragments from which RNA is read. After then, these CRISPR RNA fragments start looking for viral genes. The viral DNA is then cut by the Cas protein, which is directed by the CRISPR RNA sequence. Thus, the accumulation of virus DNA pieces functions as a sort of memory which makes it possible for the bacteria to identify and combat the virus the next time it hits (Jinek et al*.,* 2012). In 2012, Jennifer Doudna and Emmanuelle Charpentier demonstrated that it was possible to reprogram the CRISPR-Cas complex, marking a significant advancement in the use of CRISPR-Cas as a technology for editing the genomes of microbes, plants, and animals. It is possible to make the complicated cut at any chosen position in the genome by altering the CRISPR RNA molecules sequence. It is important to make sure that the CRISPR RNA sequence corresponds to the DNA sequence where the cut is to be done (Gasiunas et al*.,* 2012). Numerous articles soon followed, in which the technique was used to in various crops and for various objectives that demonstrated the great adaptability of CRISPR-Cas technology in crop improvement.

MECHANISM OF CRISPR-CAS TECHNOLOGY

According to Cong et al. (2013), the CRISPR-associated protein-9 (Cas9) and a guide RNA (sgRNA) make up the CRISPR/Cas9 system. The transactivating crRNA and the protospacer-matching crRNA, which are essential for CRISPR action, are combined to form the sgRNA. The 20 nucleotides at the 5’end of sgRNA/Cas9 target the desired gene in the genome. The target site is located directly upstream of the Protospacer Adjacent Motif (PAM) sequence (NGG for SpCas9 from *Streptococcus pyogenes*) and varies depending on the species of bacterium. A little DNA region called the PAM is situated downstream of the cleavage point. Large DNA endonuclease SpCas9 produces blunt-ended double strand breaks (DSBs) by cleaving particular genomic areas. Two routes for Cas-9 protein-induced DSB repair were discovered by Liu et al. (2019). Non-homologous end joining (NHEJ) and homology-directed repair (HDR) are the two categories of repair methods. At first, Cas9 from *Streptococcus pyogenes* was used in the majority of genome editing investigations. But thanks to recent developments, several improved forms of the wild-type Cas9 have been created (Tycko et al., 2016). There are more Cas types being researched for genome editing besides Cas9. For this reason, Cas3, Cas12, and Cas13 are also being studied. The recommended technique for genome editing is Cas12a (Mao et al., 2022).

Makarova et al. (2011) identified three types of CRISPR/Cas. Bacteria and archaea have type I CRISPR/Cas systems, identified by the unique signature of the Cas protein. Cas3 attaches to DNA using its endonuclease activity. Microbes use type II CRISPR/Cas arrays. The system includes Cas1, Cas2, Cas4/Csn2, and Cas9. Archaea and some bacteria use type III CRISPR/Cas to find DNA and RNA. Cas6, Cas10, and RAMP are present. Cas10 protein cleaves DNA after crRNA digestion. The creation of a single chimeric molecule, known as sgRNA (single guide RNA) or gRNA (guide RNA), that combines the crRNA and tracrRNA simplifies the eukaryotic genome editing platform (Koonin et al*.,* 2017). Accordingly, the tracrRNA, which has a secondary structure in the form of three hairpins required for the Cas enzyme’s recognition as well as a hairpin structure to halt its transcription, is fused to the sgRNA molecule, which contains the crRNA sequence with its spacer complementary to the target DNA sequence (protospacer) (Jinek et al*.,* 2012). Almost any particular sequence of interest in the genome can be recognized by this streamlined two-component method, provided that it is located next to a PAM site. The Cas9 enzyme first uses its recognition lobe (REC) to identify the sgRNA. After forming, the Cas9-sgRNA complex looks for a PAM site on the DNA molecule, which the Cas9 Rec lobe also recognizes. The complementary target DNA and the sgRNA can then link with 2024 nucleotides when Cas9 opens the DNA molecule directly upstream of the PAM. When there are more than three non-complementary nucleotides in a DNA site, the Cas9-sgRNA complex typically cannot identify it. It also cannot identify and cleave target DNA that has any non-complementary nucleotides in the 10-12 nucleotides close to the PAM site. The complementary and non-complementary strands of DNA are only cleaved by the HNH and RuvC Cas9 nuclease activity domains after full pairing, more precisely in the third nucleotide upstream of the PAM site. Therefore, the conserved PAM sequence in the target DNA and the pairing of its protospacer region with the spacer region (mostly the seed region) of the sgRNA dictate the Cas9-binding selectivity to the target DNA. Lastly, the organism being edited recruits DNA repair mechanisms as a result of the double-strand cleavage. The repair system can generally proceed in one of two ways: either by homologous recombination (HR) or non-homologous ends joining (NHEJ). HR repair is guided by homology, enabling the high-fidelity insertion of sequences of interest in the edited region, whereas NHEJ repair typically results in minor insertions and/or deletions (indels) surrounding the cleavage site (Anzalone et al*.,* 2019; Chen et al*.,* 2019).

Homology-directed repair is highly accurate using a homologous DNA template. HDR operates in the late S and G_2 phases of the cell cycle, requiring multiple donor DNA templates containing the target DNA sequence. Gene editing involves transferring DNA from a donor to the target genome at the predicted double-strand break location (Liu et al*.,* 2019; Yang et al*.,* 2020). Non-homologous end-joining is a process that connects DNA fragments without the need for external homologous DNA, which helps speed up DSB repairs. CRISPR/Cas is a superior method for genome modification compared to previous approaches in terms of ease, stability, and success rates. CRISPR/Cas replaced ZFN and TALEN as the preferred method for genome editing due to its superior features. CRISPR/Cas system's genome targeting abilities are being actively studied in different crops for improvement of different desirable characters.

APPLICATION OF CRISPR TECHNOLOGY IN CROP IMPROVEMENT

Enhancing crop yield

Improving yield in a short period of time is essential to meet growing global food demand which can be fulfilled by CRISPR/Cas technology as it can enhance yield attributing traits by targeting specific genes and pathways. Recently, the CRISPR/Cas9 technique was employed to boost yields in maize and rice through loss-of-function mutations of the Kernel Row Number 2 (KRN2) genes ZmKRN2 and OsKRN2, respectively, without impacting other agronomic parameters. These findings implied that these KRN2 orthologs might be the focus of crop development initiatives (Chen et al., 2022). Enhancing photosynthetic efficiency by targeting the OsSXK1 gene in rice, has improved photosynthetic rates and increased grain yield (Zheng et al., 2021). By using CRISPR to decouple the length and quantity of panicles per plant, Ideal Plant Architecture 1 (IPA1) was eliminated. This prevented IPA1 from being expressed in both the roots and the panicles, increasing the yields of rice grains (Song, 2022). The CRISPR-mediated editing of ZmRAVL also reduced ZmUPA1 and ZmUPA2 expression, which increased maize yields at different planting densities (Wei, 2022). While DUO-B1 CRISPR modification in wheat had no influence on other agronomic parameters, it enhanced the formation of extra spikelet and grain yields (Wang, 2022). CRISPR/Cas9 was used to create single and double mutants of the pectin methylesterase genes Ovule Pectin Modifier 1 and 2 (HvOPM1 and HvOPM2) in barley (*Hordeum vulgare*) (Yang, 2023). The mutants' phenotypes revealed an increase in ovule, ovarian, and grain size, which may result in increased plant yield overall. Some other achievements are given in Table 1.

Table 1. CRISPR/Cas technology in Enhancing crop yield

Crops	Targeted genes	Applications	References
Rice	OsGS2/GRF4	Increase seed size and yield	Wang et al., 2022
	RDD	Suppress miR166 recognition and influences photosynthesis	Iwamoto, 2022
	OsCKX	Enhance growth by hormone regulation	Zheng et al., 2023
	DEP1	Development of semi- dwarf plants with lodging resistance and higher grain yield	Zhang et al., 2023a
	OsNAS2	Increase zinc uptake and plant yield	Ludwig et al., 2024
	OsAPL	Increase yield in rice by improvement in nutrient transport	Zhang et al.,2024
Maize	RZ2MS9	Enhance growth	Figueredo et al., 2023
Barley	GW2.1	Reduce seed setting and yield	Kis et al., 2024

Improving abiotic and biotic stress resistance

One of the main causes of low productivity in India is the lack of suitable genotypes having resistance to different biotic and abiotic stresses with high yielding capacity (Das et al. 2021a). In order to assure sustainable food supply, agricultural output must expand by 70% to 80% by 2050. In present changing climatic conditions, crops face greater challenges due to various abiotic stresses, that is, drought, salinity, heavy metal, high radiation and extreme temperature (Veerala et al. 2024). Only 10% of cropland is designated as stress-free, indicating that most crops are exposed to one or more environmental pressures. To solve these problems, plant genome editing tools have been developed as an alternative for crop improvement. These technologies involve mobilization of genes or their regulatory elements in the genome of interest to generate stress resistant abiotic crops. By altering the plant genome in a more precise and focused manner, genome editing methods enable the development of crops with desired characteristics, such as increased resilience compared to pre-environmental modifications. Through the induction of stress tolerance traits, CRISPR has the potential to enhance plants and enable precise change of the targeted genome (Table 2).

Table 2. CRISPR/Cas technology in enhancing abiotic stress resistant

Crops	Targeted genes	Applications	References
Rice	OsDEP1, OsROCs	Enhanced heat resistance	Malzahn et al., 2019
	OsGER4	Enhanced heat resistance	Nguyen et al., 2023
	OsPUB7	Enhanced drought resistance	Kim et al., 2023
	OsTPP3	Improved salt resistance	Ye et al., 2023
	OsLCD	Generated low cadmium	Chen et al., 2023
	K5.2	Increased Ca accumulation	Wang et al., 2024a
	OsNIP3	Reduced arsenic accumulation	Xu et al., 2024
	OsMYB84	Modulated copper uptake and transport	Ding et al., 2024
	OsCOP1	Improved UV protection	Hu et al., 2024
	OsCAT2	Alleviates the oxidative stress by scavenging ROS	Shen et al., 2024
Wheat	TaIPK1	Improved iron and zinc accumulation	Ibrahim et al., 2022
	TaPGK	Enhanced cold resistance	Zhang et al., 2023b
	TaRR12	Enhanced drought resistance	Li et al., 2024a
	TaHKT1;5	Improved salt resistance	Wang et al., 2024b
Maize	ZmG6PDH1	Enhanced cold resistance	Li et al., 2023a
	ZmHSPs	Enhanced heat resistance	Li et al., 2024b
Barley	HvGSK1.1	Enhanced salinity tolerance	Kloc et al., 2024
Soybean	GmHsp90A2	Enhanced heat resistance	Jianing et al., 2022
Potato	VInv	Enhanced cold resistance	Yasmeen et al., 2022

Drought stress

The largest threat to global food security is drought stress, which is the primary factor behind the catastrophic drop in agricultural output and productivity (Joshi et al*.,* 2020). AITRs are a recently identified family of transcription factors that regulate feedback and are essential for ABA signaling. Osakabe et al.(2015) found that drought resistance was provided via a CRISPR/Cas9-created mutation in the Arabidopsis OST2 gene. Zhao et al*.* (2016) discovered that *Arabidopsis* plants' ability to withstand drought was enhanced by CRISPR/Cas9-mediated deletion of the miR169a gene. By expressing the AVP1 gene, CRISPR/Cas9 enhanced *Arabidopsis*' resistance to drought (Park et al., 2017). In order to enable drought tolerance in *Arabidopsis thaliana*, Nuñez et al. (2021) used CRISPR/Cas9 to mute the TRE1 gene. Many recent developments in drought stress adaptation and resistance can be attributed to CRISPR-Cas9 technology (Table 2).

Cold stress

Several cell compartments and metabolic pathways are involved in plants' ability to withstand cold stress (Hannah et al*.,* 2006). During the seedling stage, cold stress can have a detrimental effect on seed germination and emergence. By attaching to the promoter of the amylase gene and combining with OsJAZ9 under cold stress, OsMYB30 is a factor that lowers cold tolerance. This complex improves sensitivity to cold by decreasing the expression of the amylase gene, which leads to the buildup of maltose and the breakdown of starch (Lv et al*.,* 2017).

Salinity stress

Salt stress in plants leads to changes in gene expression and signaling pathways, resulting in physiological and morphological alterations. Salinity stress causes necrosis, premature death of old leaves, and disruption of ions in cells (Julkowska and Testerink, 2015). Using CRISPR/Cas9 technology, the OsRR22 gene which controls signaling and cytokinin metabolism in plants-was modified to increase resistance to salt stress in rice. The cytokinin pathway is hampered by OsRR22 loss of function, which increases plants' resilience to salt stress (Takagi et al*.,* 2015). Under salt stress, rice OsRR22 knockouts performed better (Zhang et al*.,* 2019). CRISPR/Cas9 was used to knock out OsmiR535 in rice, which improved its tolerance to salt stress. A 5bp deletion in the OsmiR535 coding region was found to potentially enhance rice's salt tolerance (Yue et al*.,* 2020).

Heavy metals stress

Heavy metal stress harms plant productivity in agriculture (Jha and Bohra, 2016). Heavy metals such as cadmium (Cd), arsenic (As), and lead (Pb) promote the generation of hydroxyl radicals (OH), superoxide radicals, and hydrogen peroxide (H2O2), causing oxidative stress. Loss-of-function mutants of γ-glutamyl cyclotransferase and OXP1 have shown defensive properties against heavy metal toxicity in plant molecular biology. This highlights their potential in detoxifying heavy metals and xenobiotics by increasing glutathione accumulation (Paulose et al., 2013). Long-term use of rice tainted with cadmium can result in chronic illnesses like cancer and renal failure. Thus, scientists face a problem in developing low-heavy-metal rice in places contaminated with cadmium (Bertin and Averbeck, 2006). CRISPR/Cas9 mutants can help plants deal with heavy metal stress. In rice, Cadmium absorption by roots involves transporters OsNramp1, OsNramp5, and OsCd1. OsHMA3 helps store Cadmium in the root vacuole and reduces its movement through the xylem, while OsLCT1 transports Cadmium to the grains (Chen et al., 2019). CRISPR/Cas9 was used to edit OsNramp5 and OsLCT1 genes, reducing Cadmium levels in rice grains (Tang et al*.,* 2017). OsARM1 is a regulator of arsenic-associated transporter genes in rice. It is involved in phloem expression in vascular bundles at basal and upper nodes. OsARM1 knock-out using CRISPR improves arsenic tolerance, while overexpression worsens sensitivity to arsenic (Wang et al., 2017).

UV radiation stress

CRISPR/Cas technology can boost the plant's protective mechanisms against UV damage, by enabling precise genetic modifications that enhance tolerance to DNA damage, oxidative stress, and impaired photosynthesis. The OsCOP1 gene has demonstrated potential in improving UV tolerance in rice by this technology, enhancing their resistance to UV-B radiation (Hu et al., 2024).

Oxidative stress

Oxidative stress results from the accumulation of reactive oxygen species (ROS) under various stress conditions. CRISPR/Cas technology can enhance oxidative stress tolerance in crops by targeting genes that involved in reactive oxygen species (ROS) under various stress conditions. Utilizing this technology in editing OsCAT3 gene, which is crucial for detoxifying superoxide radicals and hydrogen peroxide, can enhance rice's ability to mitigate oxidative damage (Jiang et al., 2023). This technology can offer a comprehensive approach to improving oxidative stress resilience in crops by modifying different antioxidant genes.

Biotic stresses such as pathogens, pests, and parasitic weeds severely affect crop productivity and global food security by reducing yield and quality. The pesticides which are deliberately used in agricultural practices for protection of the crops from diseases and pests are highly toxic and create potential risk to the environment and human health (Das and Baisakh, 2022). Traditional breeding for resistance is often time-consuming and limited by genetic variability. CRISPR/Cas genome editing offers a revolutionary approach to precisely modify susceptibility(S) genes, enhance innate immunity, and develop durable resistance against multiple biotic stresses in many crops (Table 3 and 4).

Table 3. CRISPR/Cas technology in improving disease resistant

Crops	Targeted genes	Applications	References
Rice	Pi21, OsSULTR3;6	Resistance to rice blast	Yang et al., 2023
	OsPUB9	Resistance to bacterial leaf blight	Kim et al., 2024
	OsCPR5.1	Yellow mottle virus resistance	Arra et al., 2024
Wheat	TaCIPK14	Resistance to stripe rust	He et al., 2023
Maize	ZmAGO18b	Resistance to southern leaf blight	Dai et al., 2023
	MCMV	Reduced viral infections	Lei et al., 2023
	Zmpdrp1	Reduced robust virus	Xie et al., 2024
Barley	BnHva22c	Reduced fungal pathogen, susceptibility	Ye et al., 2024
Soybean	Glyma05g29080	Resistance to white mold	Zhang et al., 2022a
	GmUGT	Resistance against leaf-chewing Insects	Zhang et al., 2022b
Potato	SlDCL2b	Spindle tuber viroid resistance	Tiwari et al., 2022
	PVY, PVS, PVX, PLRV	Reduced viral infections	Zhan et al., 2023
	StNRL1	resistance to late blight	Norouzi et al., 2024
Cassava	MeRPPL1	Resistance to geminivirus	Ramulifho and Rey, 2024

Table 4. CRISPR/Cas technology in developing pest resistant

Crops	Targeted genes	Applications	References
Rice	OsWRKY71, Bph15	Resistance against brown plant hopper	Li et al., 2023b
	OsHPP04	Resistance to rice root-knot nematode	Huang et al., 2023
Maize	Cry1F	Improved pest resistance	Kumari et al., 2024
Soybean	GmUGT	Resistance against leaf-chewing Insects	Zhang et al., 2022b
	GmSNAP11, α-SNAP	Resistance to soybean cyst nematode	Shaibu et al., 2022; Usovsky et al., 2023

Viral stress

CRISPR technology has shown targeting and degrading the RNA genomes of RNA viruses, preventing their replication within the host plant (Sarkar et al., 2024). This approach has been effectively demonstrated in crops like wheat and rice CRISPR/Cas9 has been employed to knock out susceptibility genes such as TaPDIL5 or OsDjA2 and OsERF that facilitate viral infection, thus providing broad-spectrum virus resistance (Távora et al., 2022). The utility of CRISPR technology not only highlights for crop trait improvement but also as a powerful tool for dissecting gene functions in plant-pathogen interactions.

Bacterial stress

CRISPR technology involves targeting bacterial virulence genes and enhancing the plant's immune response by disrupting key genes in bacterial pathogens. Editing the FERONI and SlWak1 depend on FLS gene in rice and wheat, which encodes a receptor involved in pathogen recognition, has improved the plants' ability to detect and respond to bacterial infections, thereby enhancing resistance (Huang et al., 2020; Zhang et al., 2020).

Fungal stress

Fungal diseases are a major concern for crop health and yield loss. CRISPR/Cas technology is a new hope for this problem and has been applied in various fungal species, including *Fusarium* and *Botrytis*, which are responsible for significant agricultural losses. Using CRISPR/Cas to knock out susceptibility genes that fungi exploit in wheat and soybean, which has been shown resistance to powdery mildew by making the plants less susceptible to fungal infections (Li et al., 2022; Bui et al., 2023).

Pests stress

Nowadays pest infestation problem in crops is a major concern as it not only reduces the yield but also increases the environmental pollution due to use of pesticides for their management. CRISPR/Cas technology can enhance resistance to pests in crop plants by knocking out susceptibility genes. For example, editing the ABC transporter gene in soybean has been shown to confer resistance to bollworms by disrupting the insect's ability to digest plant tissues (Amezian et al., 2024). Also another strategy is to enhance the expression of genes involved in the biosynthesis of phenolic compounds that has been shown to reduce insect preference in crops. This technology has also been used to modify genes encoding insecticidal proteins, such as Cry proteins, VIP proteins improving pest resistance in crops (Dubovskiy et al., 2024). CRISPR/Cas technology can develop nematode resistance in crop plants by targeting genes that facilitate nematode infection and reproduction which not only reduce yield losses but also save the environment by reducing the use of chemical nematicides.

Parasitic plants

Parasitic plants, such as *Striga* and *Orobanche*, attach to the host crops and extract water and nutrients as a result crop yields reduce significantly. CRISPR/Cas technology can enhance resistance to parasitic plants by targeting genes involved in host parasite interactions and develop defense mechanisms by modifying specific signaling pathways. Editing the LGS1 gene in sorghum by this technology developed resistance to *Striga* by disrupting the production of strigolactones, which are essential for *Striga* seed germination and attachment (Makaza et al., 2023).

Improving crop quality

A major factor in determining the market value of crops has been crop quality. Generally speaking, both internal and external characteristics influence crop quality. Physical and aesthetic qualities including size, color, texture, and scent are examples of external quality features. The internal quality factors, on the other hand, consist of bioactive substances like carotenoids, lycopene, γ-aminobutyric acid, flavonoids, and others, as well as nutrients like protein, carbohydrate, fats, etc. Crop quality enhancement using CRISPR/Cas9 concentrated on the fruit's texture, nutritional value, edible quality, and physical beauty (Table 5). Food products that are nutritious and healthy are becoming more and more popular. In order to meet the needs of this expanding industry, researchers have been urged to develop new items. Numerous nutrients found in fruits and vegetables have anti-oxidant, anti-inflammatory, and anti-cancer properties. Breeding initiatives have been put in place to bio-fortify a variety of nutrients, such as the amounts of iron, zinc, γ-aminobutyric acid (GABA), and carotenoid in different crops. It has been attempted to use gene editing for biofortification in order to provide high-quality nutrients to satiate the "hidden hunger."

Table 5. Crop quality and nutritional improvement using CRISPR technology

Crop	Targeted Gene	Associated Traits	References
Rice	CrtI, PSY	High Beta carotene	Dong et al., 2020
	OsNramp5	Low Cd accumulations	Tang et al., 2017
	OsPLDα1	Low phytic content	Khan et al., 2019
	SIGAD2. SIGAD3	High GABA content	Nonaka et al., 2017
	OsAUX5, OsWRKY78	Control grain essential amino acid accumulation	Shi et al., 2023
Wheat	TalPK1	increase iron and zinc content	Ibrahim et al., 2022
	TaPDI	Accumulate storage protein.	Hu et al., 2022
Barley	HGGT, HPT	Increase vitamin E biosynthesis	Zeng et al., 2020
Soybean,	GmFAD2	Increase fatty acid	Zhou et al., 2023
Potato	StSBE1, StSBE2	High amylose content	Tuncel et al., 2019
Rapeseed	BnTT8	High oil production and GPC	Zhai et al., 2020
Sweet Potato	IbGBSSI, IbSBEII	High amylose content	Wang et al., 2019
Cassava	CYP79D1	Lower levels of cyanide	Juma et al., 2022
Grape	IdnDH	Low tartaric acid	Ren et al, 2016

Increasing γ-aminobutyric acid content

A non-protein amino acid inhibitory neuro-transmitter, GABA helps regulate blood pressure and reduce anxiety (Nuss, 2015). Thus, the food business has turned its attention to creating new foods that are high in GABA. One important enzyme that catalyzes the conversion of glutamate to GABA is glutamate decarboxylase (GAD). GAD activity is negatively regulated by its C-terminal autoinhibitory domain. Using CRISPR/Cas9, the C-terminal has been entirely removed to enhance the amount of GABA. Mutant tomatoes showed a seven-fold increase in GABA accumulation (Nonaka et al., 2017).

Increasing carotenoid content

Carotenoids have been implicated in the prevention of eye-related diseases and antioxidant processes. However, carotenoids must be consumed through diet because humans are unable to produce them. Furthermore, phytoene and lycopene lower the risk of cardiovascular disease and cancer. In the past, scientists used traditional genetic engineering to produce β-carotene in rice while simultaneously introducing the *CrtI* and *PSY* genes. However, despite a stringent GM regulatory environment, such genetically modified (GM) golden rice caused widespread alarm. Since golden rice might not contain enough β-carotene to completely cure vitamin A deficiency, and because planting and eating golden rice could result in allergies or antibiotic resistance, many anti-GMO activists maintain that this effort is overly optimistic. Rice, tomato, and banana carotenoid biofortification has been achieved by the use of CRISPR/Cas9-mediated genome editing. Because there is no external gene integration in host genomes, those generated by this method show promise in evading a GM regulatory regime. In general, carotenoid biofortification was accomplished using two types of techniques. First, the carotenoid biosynthesis pathway is subjected to carbon flux due to the overexpression of phytoene synthase genes caused by CRISPR/Cas9-mediated knock-in. In this way, a caroteno genesis cassette with the genes *CrtI* and *PSY* has been incorporated into the rice target site, producing marker-free gene-edited mutants with a dry weight of 7.9 µg/g β-carotene (Dong et al., 2020).

Increasing fatty acid composition

Olive oil is rich in monounsaturated fatty acids (MUFA), such as oleic acid (18:1). Diets high in oleic acid are beneficial to the cardiovascular system. Trans- and saturated fatty acids are frequently cited as “unhealthy” fats and associated with heart disease (Briggs et al., 2017). Soybean oil, the most often produced and consumed edible oil, has just 20% oleic acid, which is significantly less than that of olive oil (65-85%).

Eliminating anti-nutrients

Phytic acid cannot be metabolized by humans because they lack the appropriate degradation enzymes. Because phytic acid can interact with minerals and proteins to create complexes, consuming large amounts of phytic acid will limit the absorption of these nutrients (Oatway et al., 2001). CRISPR/Cas9 has been used to knock out an ITPK gene that code for an enzyme that catalyzes the penultimate step of phytate production, thereby lowering the amount of phytic acid in rapeseeds. Without affecting plant performance, the ITPK mutants showed a 35% decrease in phytic acid (Sashidhar et al., 2020).

Biological nitrogen fixation

The production of major crops like rice, maize, and wheat steadily increased between the 1930s and the late 1960s as a result of the development of high-yielding cereal varieties, chemical fertilizers, new irrigation and cultivation techniques, and modern management techniques. For plants to absorb atmospheric nitrogen gas, it must be converted into organic nitrogen. More than 50% of the global nitrogen fixation (estimated at 413 million tons in 2010) comes from biological nitrogen fixation (BNF), an environmentally friendly alternative to industrial nitrogen fixation by the energy-intensive Haber-Bosch process, which currently produces 120 million tons of nitrogen fertilizer annually (Fowler et al., 2013). *Rhizobium rhizogenes* (formerly *Agrobacterium rhizogenes*) mediated hairy root transformation, which was the initial application of CRISPR/Cas9 for soybean genome modification. The GmU6-10 and GmU6-16g-1 promoters were found to be more effective than the AtU6-26 promoter in transgenic hairy roots when the effectiveness of genome editing using sgRNAs driven by different endogenous and exogenous RNA polymerase III (pol III) promoters was assessed.However, when employing the soybean U6 promoter, the TALENs’ mutation efficiency was significantly lower than that of the Cas9/sgRNA method. More encouragingly, homozygous T1 plants with the anticipated precise DNA knock-in were achieved after Cas9-sgRNA and donor DNA fragments were effectively transformed into soybean utilizing the particle bombardment approach (Li et al, 2015). The sgRNA component of the Cas9/sgRNA complex plays a major role in determining the specificity and effectiveness of CRISPR-mediated genomic alterations. Designing suitable sgRNAs that reduce the possibility of generating DSBs in off-target locations in the genome is therefore crucial. CRISPR-PLANT and CRISPR-P are two example online platforms that are frequently utilized for sgRNA design in legumes (Xie et al., 2014).

CHALLENGES OF CRISPR TECHNOLOGY IN CROP IMPROVEMENT

Although CRISPR/Cas technology has rapidly evolved from its discovery to become one of the most versatile genome-editing tools with a revolutionary potential but a number of scientific, technical, regulatory, and ethical challenges still constrain its widespread use in crop improvement. Understanding these challenges is essential to fully harness CRISPR’s potential for sustainable agriculture and global food security.

Scientific and technical challenges

One of the most fundamental challenges in CRISPR/Cas-mediated crop improvement is off-target editing, where unintended genetic modifications occur at sites similar to the intended target. Such off-target effects may lead to unpredictable phenotypes or even compromise plant health and productivity. Although the use of high-fidelity Cas variants such as SpCas9-HF1, eSpCas9, and Cas12a has improved precision, the complete elimination of off-target mutations remains difficult, especially in polyploid crops like wheat that have complex genomes (Schaart *et al*. 2021). Moreover, the efficiency of the CRISPR system can vary widely depending on factors such as target sequence, GC content, and chromatin accessibility, which influence Cas binding and cleavage efficiency.Another significant issue involves delivery of CRISPR components into plant cells which are often species-specific, labor-intensive, and have low transformation efficiencies in many recalcitrant crops like legumes, sugarcane, and woody perennials In addition, gene redundancy in polyploid species poses a challenge because multiple copies of the same gene may mask the effects of editing a single locus, necessitating multiplexed editing strategies. Grain yield is a polygenic controlled complex character with low to moderate heritability owing to environmental effects and also greatly influenced by many interrelated component traits, which are also mostly polygenic (Das and Baisakh, 2019; Prusti and Das, 2020). Also other traits such as drought and salt tolerance, nutrient use efficiency etc are governed by complex polygenic networks, making single-gene edits insufficient for major improvements.

Regulatory and policy issues

One of the most contentious challenges surrounding CRISPR/Cas technology lies in the regulatory and policy frameworks that govern its use. Different countries have adopted divergent stances toward genome-edited crops, creating uncertainty for global trade and innovation due to lack of uniform global policy which harmonization impedes international research collaboration and commercialization of gene-edited varieties.Additionally, biosafety evaluation and traceability present practical difficulties. Unlike transgenic crops, which contain identifiable foreign DNA sequences, CRISPR-induced edits are often indistinguishable from natural mutations, making detection and labeling challenging (Schaart et al., 2021).

Ethical and socio-economic concerns

Many consumers still conflate gene editing with traditional genetic modification (GMOs), leading to skepticism and resistance. Transparent communication from researchers and policymakers, effective public engagement, ethical education, and open dialogue about the benefits and risks of CRISPR-edited crops are essential for building trust and ensuring responsible innovation.

Future pathways to overcome challenges

Overcoming these challenges requires a multi-pronged and globally coordinated approach. Technically, the development of next-generation CRISPR systems such as base editors, prime editors, and RNA-targeting Cas variants (Cas13, Cas14) promises to minimize off-target effects and expand the editing toolkit (Zhang et al., 2023c). Improvement in DNA-free editing techniques—using RNP complexes or transient expression systems—can help produce transgene-free crops, simplifying regulatory approval. On the policy front, harmonizing international regulations and establishing science-based risk assessment protocols will be critical to promoting global acceptance. Strengthening public communication and ethics education can bridge the gap between scientific innovation and societal trust. Capacity building in developing countries is equally vital. Investment in local genomic resources, bioinformatics infrastructure, and public-sector breeding programs can ensure that CRISPR technology benefits smallholder farmers and contributes to sustainable development. Collaboration between universities, research institutes, and international agencies will further accelerate progress while maintaining transparency and safety.

FUTURE PROSPECTS AND SDG OBJECTIVES

The future prospects of CRISPR/Cas technology in crop improvement are exceptionally promising, offering transformative potential for agriculture, food security, and environmental sustainability.CRISPR's capacity to precisely modify genes by cutting and pasting at specified locations is one of its biggest benefits. This accuracy makes it possible to alter several genes at once, transport proteins to specific genes to adjust their activity, and create completely new genetic pathways.Advances in genome editing, such as base editing and prime editing, offer unprecedented precision in modifying plant genomes, allowing for the enhancement of traits like drought tolerance, disease resistance, and nutritional content (Chen et al., 2024). The capacity to edit multiple genes simultaneously through multiplexed CRISPR/Cas systems also opens the door to developing crops with stacked traits, such as drought and heat tolerance coupled with improved nutritional profiles, thereby addressing multiple challenges in a single breeding cycle. CRISPR/Cas technology can be used to develop edible vaccines by engineering plants which are consumed as food. The edible vaccine has the potential to solve the problem of bioterrorism by immunizing against a wide range of different dreaded viruses and can save the earth from any future epidemic and pandemic (Das et al. 2021b). In future the integration of CRISPR/Cas with other technologies such as speed breeding, high-throughput phenotyping, and artificial intelligence-driven predictive models can enhance the efficiency of gene editing processes, enabling the rapid development of climate-smart crops tailored to specific environments. Furthermore, CRISPR/Cas applications are increasingly being explored to improve nutrient use efficiency, nitrogen fixation, and water-use efficiency, which can significantly reduce reliance on chemical fertilizers and irrigation, mitigating greenhouse gas emissions and environmental degradation.

The integration of CRISPR/Cas technology into sustainable agriculture is closely aligned with several United Nations Sustainable Development Goals (SDGs), particularly SDG-2 (Zero Hunger), SDG-12 (Responsible Consumption and Production), SDG-13 (Climate Action), and SDG-15 (Life on Land). By enabling the development of high-yielding, nutrient-dense, and climate-resilient crops, CRISPR/Cas contributes directly to food security and nutritional adequacy in both developing and developed countries. Crops engineered for enhanced micronutrient content, biofortification, or reduced allergens can combat malnutrition and improve public health, directly supporting SDG-2. Additionally, CRISPR / Cas- mediated improvements in resource-use efficiency contribute to SDG-12 by promoting sustainable production practices, reducing chemical inputs, and lowering the environmental impact of agriculture. Climate-resilient crops generated through CRISPR/Cas address SDG-13 by helping agricultural systems adapt to changing climatic conditions, ensuring stable food production despite increasing droughts, heat waves, and erratic rainfall patterns. Moreover, by preserving wild relatives and landrace varieties while improving cultivated crops, CRISPR/Cas supports biodiversity conservation, aligning with SDG-15. The technology can also facilitate precision breeding strategies that reduce the need for land expansion, helping conserve forests and natural habitats while sustaining agricultural output.

The future of CRISPR/Cas technology will depend not only on technical advancements but also on regulatory harmonization, ethical governance, and public acceptance. As the scientific community continues to demonstrate the safety, efficacy, and benefits of genome-edited crops, policies are gradually evolving to accommodate non-transgenic CRISPR/Cas products without imposing undue barriers. Public engagement, transparent communication, and capacity-building programs are critical to ensuring equitable access to this technology, particularly for smallholder farmers and resource-limited regions. The integration of CRISPR/Cas with digital agriculture, remote sensing and data-driven decision-making will further enhance its impact, enabling precision-targeted interventions that maximize productivity while minimizing environmental harm. In the long term, CRISPR/Cas technology holds the potential to transform global agriculture into a system that is not only productive and resilient but also ecologically sustainable and socially inclusive. By aligning its applications with the SDGs, CRISPR Cas can serve as a cornerstone of a new green revolution, enabling humanity to feed a growing population, protect natural resources, and build a more sustainable and equitable future.

CONCLUSION

The CRISPR/Cas technology has emerged as one of the most powerful tools in modern agricultural science, reshaping the future of crop improvement and sustainable food production. It offers an efficient pathway to develop crops that are not only higher yielding but also more resilient to climate stress, pests, and diseases with promising quality and nutritive value. The ability to edit specific genes without introducing foreign DNA also makes CRISPR-based crops more acceptable to the public and regulators compared to older genetically modified organisms (GMOs). This distinction is essential for promoting wider acceptance of genome-edited crops and enabling their safe and responsible use in agriculture. Furthermore, the integration of CRISPR/Cas with bioinformatics, speed breeding, artificial intelligence, and high-throughput phenotyping are leading to a new era of precision agriculture, where crop development is guided by data and molecular insight rather than trial and error. Ultimately, CRISPR/Cas represents more than a scientific tool. It embodies a new philosophy of agriculture grounded in sustainability, innovation, and responsibility. If applied ethically and inclusively, it has the potential to secure food for future generations while preserving natural ecosystems.

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Techno-economic feasibility of conventional and eco-friendly refrigerators: A horizontal analysis

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ABSTRACT

Refrigerators have become an inseparable part of the lives of the millions of people around the globe. The cool temperature in the refrigerator slows down the enzyme activity and bacterial reproduction in the food. Protection of environment by eco-fridge is need of the hour. A study was conducted to compare the techno-economic feasibility of conventional and eco-friendly refrigerator in terms of quality of food, Coefficient of Performance (COP) and Performance of System (POS). The food items namely kheer (traditional Indian recipe prepared with milk, sugar and rice), custard and salad were selected for testing. The samples were then evaluated for their organoleptic appeal. A significant difference was found in the quality of food kept in both the refrigerators, at the 5 and 1 per cent level of significance. The study also revealed that the eco-fridge is more efficient and economical appliance than conventional refrigerator in terms of COP attained during no-load and full-load conditions.

Key words: Coefficient of performance, conventional refrigerator, eco-fridge, organoleptic characteristics

INTRODUCTION

Equipment are valued for the work that they can do, as well as for the ways in which they reduce time and effort required for many routine tasks. Refrigeration can substantially reduce the rate at which food will deteriorate. Low temperatures slow down the growth of microorganisms and the rate of chemical (including enzymatic) changes in food. These are two of the main causes of food spoilage (https://koolit.co.uk). Different parts of a refrigerator may operate at different temperatures. In older style refrigerators, the upper shelves are often slightly colder than the lower shelves. In more modern appliances, the temperature is maintained relatively uniform throughout. The warmest and coldest areas inside the refrigerator are dependent on the types of model (https://www.csiro.au). To promote sustainable consumption, one needs to look at the aspect of sustainable production as well. Refrigerators have become an inseparable part of the lives of the millions of people around the globe. Rapid communication and increasing access to commodities plus changes in lifestyle have spurred the need to stock food and beverage in refrigerator for longer. Storage and transportation of medicines are another important area of usage. Also, consumer choices significantly influence the environmental impact of cooling appliances (Kim and Lee, 2023). Small adjustments in usage habits and careful selection of energy-efficient products can result in substantial reductions in energy consumption and greenhouse gas emissions (Rohella and Biswal, 2008). By embracing sustainable cooling practices, individuals need to be updated and play a crucial role in the collective effort to combat climate change and safeguard the environment (TERI, 2023). It is known that reduction in temperature will slow down the processes of decay and spoilage in many foods. The purpose of a freezer is to stop bacterial growth completely by freezing the water present in the food. Generally, the consumer shopping for new refrigerator look for one that cools food efficiently, maintain temperature evenly and minimizes spoilage. Food occupies the first position in the hierarchical needs of man. The refrigerator is one of those miracles of modern living that totally changed the life style. Prior to refrigeration, the only way to preserve meat was to salt it, and iced beverages in the summer were a real luxury (https://www.danfoss.com).

Kumar (2003) revealed that the cool temperature in the refrigerator slows down the enzymes activity and bacterial reproduction in the food. This preserves food quality, taste, texture and thereby keeps food safer for a longer time. Gerster (1997) studied that all the early refrigerants like methyl chloride, sulphur-dioxide, carbon dioxide and ammonia do have disadvantages like flammability, toxicity, time of preservation etc, which restrict their general use. Nowadays, most common technology recommended in refrigerator is "Hydrocarbon Technology" which protects the ozone layer (GPI, 2025). Also, a number of inventions have prompted the accessibility to varied choices of these eco-fridges. Present study helps to some extent in protecting the environment by usage of eco-fridges (Kumar and Singh, 2024).

MATERIALS AND METHODS

Conventional refrigerator

Any refrigerator that has been produced through old technology i.e. HFC and CFC technology as refrigerants can be called as conventional refrigerator.

Eco-fridge

Green Fridge is a popular name for an environmental friendly refrigerator. In which "hydrocarbon technology" is used for both cooling and insulation. The name is given by "Green peace International Association" (Anonymous, 1999). According to a recent AI-generated overview by Google, an eco-friendly refrigerator-often referred to as an 'ecofridge'- is designed to minimize environmental impact and energy consumption. This is achieved through features such as energy-efficient compressors and the use of environmentally safe refrigerants, which enhance cooling performance while reducing waste.

To find out the techno-economic feasibility of conventional and eco-friendly refrigerator, experiments were conducted.

Selection of equipment

Eco-fridge (Samsung) and conventional fridge (BPL), were selected for the experiment as they were easily available and reachable.

Weighing balance, cups and spoons for measurement of raw materials and cooked food products were also used.

Selection of recipe

Kheer, Custard, Salad + green leafy vegetables (Radish, tomato, capsicum, coriander and spinach)

Fig. 1-3. Selected food items for the experiment

The three different food items (Fig. 1, 2 and 3) have been selected for the experiment, which were kept in two different refrigerators for at least 48 hours. This was done to check the variation due to effect of appliances.

Sensory evaluation of the cooked food

To evaluate the sensory characteristics of different cooked food items that were kept in two different refrigerators, a panel of six judges was selected using a score card having 9 point Hedonic scale (Sharma et al, 2025).

Coefficient of performance and performance of system

It measures the efficiency of a refrigerator. It is defined as the ratio of the quantity of heat extracted per cycle from the content of the refrigerator to the mechanical work 'w' done by the external agency to do so. It is denoted by:

$$\beta = \frac{Q_2}{w}$$

Smaller the amount of mechanical work done in removing heat Q_2, the greater will be the coefficient of performance.

$$\therefore\ w = Q_1 - Q_2$$

$$\therefore \beta = \frac{Q_2}{Q_1 - Q_2} = \frac{1}{\frac{Q_1}{Q_2} - 1}$$

However : $\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$

$$\therefore\ \beta = \frac{1}{\frac{T_1}{T_2} - 1} = \frac{T_2}{T_1 - T_2}$$

- In actual practice β varies from 2 to 6.
- Lesser the difference in the temperature of the cooling chamber and the atmosphere, higher is the COP of refrigerator.
- In case of refrigeration, the COP may be much higher than 1. The refrigerator work performance decreases due to formation of too much ice. However, there is practically no change in T_1. This decreases the value of β. However, if the refrigerator is defrosted, T_2 shall increase and thus the value of β. It is necessary to defrost the refrigerator. In actual refrigerator the vapour of some low boiling point liquid (ammonia or freon – 12) act as the working substance. The working substance absorbs a certain quantity of Q_2 from the cold body or sink at lower temperature. $T_2$is called refrigeration effect. In the household refrigerator, the ice- cubes in the freezer compartments and food constitute the cold body (Patel and Rao, 2024).

The COP of the conventional and eco-friendly refrigerator has been measured in three different seasons i.e. March (late winter), June (peak summer) and August (spring) seasons. The measurement included the electricity consumption in terms of electrical potential in volt and current in ampere and simultaneously the prevailing average inside temperature of refrigerator and outside ambient temperature.

These experiments were extended for both types of refrigerator in both condition i.e. no-load and full-load conditions. The basic idea behind these measurements is to find out variation in COP in different conditions in different refrigerators. The COP obtained may be useful to predict the performance of refrigerator from the environment point of view. A multimeter comprising voltmeter and ammeter was connected to the refrigerator during experiment to find out total electricity consumption (Deshpande, 2024).

RESULTS AND DISCUSSION

To determine the techno-economic feasibility of conventional and eco-friendly refrigerators, experiments was conducted where in each of the three food items were kept in two different refrigerators for 48 hours to determine quality of food (Sarafarazi and Mahawer, 2023). The food items consisted of kheer, custard and salad. For the sensory study, 9-point Hedonic Scale was used, then, the results were analyzed by using Standard Deviation and *t*-test.

Table 1. Organoleptic characteristics (Mean ± SD score) of kheer stored in the two refrigerators

Sl. No.	Characteristics	Eco-fridge Mean ± S.D. (SE)	Conventional fridge Mean ± S.D. (S.E.)	Eco-fridge v/s Conventional refrigerator t values
1.	Appearance	8.33 ± 0.469 (0.192)	6.66 ± 0.326 (0.133)	6.637 **
2.	Colour	8.5 ± 0.5 (0.204)	6.83 ± 0.9 (0.368)	3.634 **
3.	Flavour	8.16 ± 0.68 (0.28)	6.33 ± 0.943 (0.386)	3.519**
4.	Texture	8 ± 0.479 (0.196)	6.5 ± 0.574 (0.235)	4.504**
5.	Taste	7.66 ± 0.748 (0.306)	6.5 ± 0.957 (0.392)	2.139*
6.	Overall acceptability	8±0.479 (0.196)	6 ± 0.943 (0.386)	4.237**

Level of significance: ** (P<0.01); * - (P<0.05)

Table 1 depicts the mean ± SD (SE) and significance of kheer evaluated by the panel members. The results showed that appearance of kheer was significantly different (P<0.01) between both groups (i.e. Eco-fridge and conventional fridge). The results were also same in all the other cases of colour, flavour, texture and overall acceptability. While in the case of kheer, taste was significantly different (P<0.05) between two groups. Table 2 illustrates the organoleptic characteristics score (mean ± SD) of custard by the panel of judges and their significant difference. The results showed that the appearance, flavor and taste scores of custard were significantly different (P<0.01) between both the groups (i.e. Eco-fridge and conventional refrigerator) while in the case of colour and overall acceptability, the scores were significantly different at 5 per cent level, i.e., (P<0.05). There is no significant difference in texture score of custard between both the groups.

Table 2. Organoleptic characteristics (Mean ± S.D. scores) of custard stored in the two refrigerators

Sl. No.	Characteristics	Eco-fridge Mean ± S.D. (S.E.)	Conventional fridge Mean ± SD (S.E.)	Eco-fridge v/s Conventional refrigerator t values
1.	Appearance	8.33±0.46 (0.188)	6.83±0.689 (0.282)	4.065**
2.	Colour	8±0.81 (0.33)	6.33±1.630 (0.668)	2.056*
3.	Flavour	8±0.57 (0.23)	6.83±0.574 (0.235)	3.111**
4.	Texture	8±0.57 (0.23)	6.5±0.741 (0.303)	1.394
5.	Taste	7.66±0.47 (0.19)	6.16±0.692 (0.283)	4.03**
6.	Over all acceptability	7.83±0.45 (0.18)	6.66±0.9 (0.368)	2.611*

Level of significance: ** - (P<0.01); * - (P<0.05)

Table 3 depicts the organoleptic sensory scores (mean ± SD) of the salad as evaluated by the panel members, along with their statistical significance. The results depicted that the appearance, flavor, texture and overall acceptability scores of salad were significantly different in case of both the groups i.e. (P<0.01). Taste-wise, there was no significant difference in salad stored in both the refrigerators. However, the colour score varied significantly at 5% level of significance. According to organoleptic evaluation conducted by Sarfarazi and Mahawer (2023), sensory attributes such as taste, flavor, and texture exhibited a progressive decline with increasing ambient storage duration from 0 to 120 days.

Table 3. Organoleptic quality (Mean ± S.D. score) of salad stored in both the refrigerators

Sl. No.	Characteristics	Eco-fridge Mean ± S.D. (S.E.)	Conventional fridge Mean ± SD (SE)	Eco-fridge V/s Conventional refrigerator t values
1.	Appearance	7.66±0.479 (0.196)	4.33±1.6 (0.655)	4.469**
2.	Colour	7.33±0.748 (0.306)	4.66±2.13 (0.87)	2.65*
3.	Flavour	7.33±0.748 (0.306)	3.83±2.19 (0.89)	3.391**
4.	Texture	7.33±0.479 (0.196)	3.83 ± 2.21 (0.90)	3.468**
5.	Taste	6.83±2.414 (0.989)	6.66±2.19 (0.89)	0.16
6.	Overall acceptability	7.66±0.479 (0.196)	4.46±1.94 (0.795)	7.766**

Level of significance:** - ($P<0.01$), * - ($P<0.05$)

As the Samsung bio-fresh model claims that the heart of bio-fresh refrigerator is bio-ceramic technology which is used in vegetable compartment. This is a unique property of emitting infra rays which helps retain moisture and keep vegetable fresher and tastier for a longer period (FAO, 2025). It is true because when the vegetables were kept in both the refrigerators for 48 hours, the vegetables which are kept in bio-fresh refrigerator are more liked by panel members as compared to the vegetables kept in conventional refrigerator. Further, the food item which were kept in bio-fresh refrigerator is more appealing, appetizing and fresh than the food item kept in conventional refrigerator (TERI, 2025).

Second experiment was performed to find out coefficient of performance (COP) of the refrigerator. For comparative study of two refrigerators, no-load and full-load testing of both the refrigerators with observation period of 8 hours was done.

The no-load testing and full-load testing of conventional as well as eco-friendly refrigerator has been made as per procedure mentioned in the materials and methods section. The experiment has been extended in different season's i.e. March (late winter). June (Peak summer) and August (spring season). It has been observed from Table 4 that the COP of conventional refrigerator during March month comes out to 0.43, where as in the June and August these are 0.38 and 0.42, respectively in no-load condition. Further, it was also observed that the power consumption during March, June and August in no-load testing condition were 0.77, 0.836 and 0.79 kWh.

During March the outside ambient temperature was less, therefore less electrical work was made to remove required heat from the refrigerator space resulting in maximum COP and less power consumption. However, because of high prevailing temperature in June, the requirement of power for removing heat was more hence less COP was obtained.

Table 4. No-load testing of conventional refrigerator

Sl. No.	Month	Potential (in volts)	Current in (Ampere)	Power consumed in kWh	Avg. outside Temp. (T_1)	Avg. inside Temp. (T_2)	COP
1.	March	220	3.5	0.77	23	7	0.43
2.	June	220	3.0	0.836	36	10	0.38
3.	August	220	3.6	0.79	30	9	0.42

Table 5. Full-load testing of conventional refrigerator

Sl. No.	Month	Potential (in Volts)	Current in (Ampere)	Power consumed in kWh	Avg. outside Temp. (T_1)	Avg. inside Temp. (T_2)	COP
1.	March	220	3.7	0.814	24	7	0.41
2.	June	220	3.9	0.858	37	10	0.37
3.	August	220	4.1	0.902	35	9	0.40

Table 5 depicted that the COP of conventional refrigerator during full-load condition in the month of March, June and August were 0.41, 0.37 and 0.0404, respectively. Further it was also observed that the power consumption during March, June and August were 0.814, 0.878 and 0.902 kWh. It is similar to COP obtained. The COP was further less in case of full-load testing. It was an account of more power consumption for keeping moderate temperature inside the refrigerated space.

Table 6 illustrates the COP measurement of eco-friendly refrigerator that comes out to be 0.47, 04 and, 0.44, respectively in the months of March, June and August during no-load testing. The consumption of electricity was also in the same proportion as that of COP in respective month.

It was observed from Table 7 that the COP in full-load condition were less as compared to no-load condition; they were 0.44, 0.38 and, 0.42, respectively for the months of March, June and August.

Table 6. No-load testing of eco-friendly refrigerator

Sl. No.	Month	Potential (in volts)	Current in (Ampere)	Power consumed in kWh	Avg. outside Temp. (T_1)	Avg. inside Temp. (T_2)	COP
1.	March	208	2.6	0.660	25	8	0.47
2.	June	208	2.8	0.832	28	8	0.40
3.	August	108	3.0	0.730	26	8	0.44

Table 7. Full-load testing of eco-friendly refrigerator

Sl. No.	Month	Potential (in volts)	Current in (Ampere)	Power consumed in kWh	Avg. outside Temp. (T_1)	Avg. inside Temp. (T_2)	COP
1.	March	208	2.7	0.70	26	8	0.44
2.	June	208	3.0	0.835	29	8	0.38
3.	August	208	3.3	0.75	27	8	0.42

Nongthombam (2020) confirms that like ZECC, ecofridge for storing food items involves evaluating their performance based on several key factors such as cooling efficiency, shelf life extension, cost, maintenance, and suitability for different climates and products without affecting our environment. Hence, the conditions are always maintained the same. This is also important from refrigeration point of view. Sensory evaluation scores exhibited that samples stored in eco-fridge obtained highest scores in texture, colour, appearance and taste, except in the case of flavour, taste and colour of salad. So overall acceptability of samples stored in eco-fridge is more than conventional refrigerator. Similarly, the co-efficient of performance of eco-friendly refrigerator is better as compared to conventional refrigerator in terms of its COP attained during no-load and full-load condition. Since the COP is more for eco-friendly refrigeration the heat losses to atmosphere is less in this type of refrigerator. Overall, it was found that eco-fridge performance is better than conventional refrigerator in terms of quality of food and coefficient of performance (Intarcon, 2025). A study by Hoffman et al. (2021) also corroborates and confirms the present study in terms of efficiency of eco-fridge performance.

CONCLUSION

From the study, it was concluded that the performance of eco-friendly refrigerators is better as compared to conventional refrigerator in terms of its COP attained during no-load and full-load condition. Since, the COP is more for eco-friendly refrigerator, the heat losses to atmosphere is less in this type of refrigerator. This reduces the pollution effect of refrigerating unit. Further, it was also observed that power consumption in eco-friendly refrigerator is varying according to load condition, similar to that of the conventional refrigerator, but the average internal temperature throughout the various seasons is more or less the same i.e. 8°C. Overall sensory acceptability score of samples stored in eco-fridge is more than conventional refrigerator. So, eco-fridge is more efficient and economical appliance than conventional refrigerator in terms of quality of food stored and COP attained during no-load and full-load condition.

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New distributional record of two weedy amaranths as leafy vegetables from Odisha, India

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ABSTRACT

Amaranthus, commonly called as "amaranths", is a wide taxonomic group with a large diversity of species and varieties, embodies several weedy and domesticated forms of great economic importance. A number of species are cultivated as leafy vegetables, pseudo-cereals, food, fodder, medicines and ornamental plants. These are short-lived annual plants which develop vigorously and adapt easily to new environments. During the survey for germplasm collection of minor leafy vegetables and wild relatives of crop plants in parts of Odisha, the occurrence of naturalised populations of two species of wild/weedy *Amaranthus* viz. *Amaranthus blitum* L. and *A. dubius* Mart. ex Thell. were explored from different phyto-geographical zones of the state. On elucidative review, the natural occurrence of these species in the state is found to be new taxonomic records for the flora of Odisha. The present communication deals with information on its taxonomic description, phenology, germplasm collection and photographs to facilitate easy identification and their sustainable use.

Key words: *Amaranthus,* leafy vegetables, new record, Odisha

INTRODUCTION

The genus *Amaranthus* L. commonly called as 'amaranths' belonging to the family Amaranthaceae, subfamily Amaranthoideae, is a large plant group harbouring several cultivated and weedy species of great economic importance. The members are annual or short-lived perennial herbs grow vigorously and adapt easily to new environments (Norman, 1992). Although a number of these species are potential, majority are neglected and underutilized crops. Most of the members are cosmopolitan in distribution, found almost in all temperate and tropical countries. The primary centres of diversity are Central and South America, India and South East Asia, whereas the secondary centres of diversity are West and East Africa. A number of amaranth species are cultivated as leafy vegetables, pseudocereals, food, fodder, cosmetics, medicine and ornamental plants (Prakash and Pal, 1991; Shukla et al., 2003). *Amaranthus* is a wide taxonomic group with a large diversity of species, with specific traits such as resistance to biotic and abiotic stresses, high yields, nutritive, nutraceutical and market qualities (Enoch et al., 2014). It shows a wide variety of morphological diversity among and within certain species resulting in nomenclatural confusions and misapplication of several names. The phylogenetic relationship and taxonomic delimitation in genus *Amaranthus* are still not resolved with absolute clarity. The genus *Amaranthus* comprises 70-75 species, of which approximately more than half are native to the Americas (Costea et al., 2001; Mosyakin and Robertson, 2003; Iamanico, 2015), however, it constitutes 92 accepted species (POWO, 2021). Mosyakin and Robertson (1996, 2003) divided the genus into three subgenera viz. *Acnida, Amaranthus,* and *Albersia* based on morphological parameters and reported 70 species consisting of inflorescences ranging from red, purple, green and gold. Majority species show unisexual flowers and compressed, black, and shiny seeds.

In India, the genus *Amaranthus* is represented by 19 species mainly confined to tropical and peninsular region. Several species are used as ornamentals, food and medicines, and some of them are able to escape from cultivation as weedy relatives on fallow lands, wastelands and roadsides (Das, 2016; Kamble and Gaikwad, 2021). These are short-lived annual plants which develop vigorously and adapt easily to new environments. In India, many of the species in this genus are edible popular leafy vegetables and some are domesticated for their leaves for culinary use (Khurana et al., 2013).

MATERIALS AND METHODS

While conducting exploration missions for germplasm collection of minor leafy vegetables and wild relatives including other crop plants during 2014-2025, the first author observed the occurrence of naturalised populations of two species of wild/ weedy *Amaranthus* in different locations of phyto-geographical zones of Odisha. The seed germplasm were collected from the live plants in ripe capsule (utricle) stage in natural habitats and deposited in the National Gene Bank, ICAR-NBPGR, New Delhi for long term conservation. The plant specimens bearing both vegetative and floral parts were deposited in the herbarium of the centre along with one set at the National Herbarium of Cultivated Plants (NHCP), ICAR-NBPGR, New Delhi. The live plants and the herbarium specimens were critically studied and the morphological features of the plant were examined and the distinctive characters were recorded. The photographs of the plant species in the natural habitat were taken for reference.

After thorough examination of morphological characters of the live plants and consultation of herbarium specimens at Central National Herbarium, CAL, Howrah, along with perusal of relevant literature, these two species of wild amaranths were identified as *Amaranthus blitum* L. and *A. dubius* Mart. ex Thell. On verification of published flora (Haines, 1924; Mooney, 1950; Saxena and Brahmam, 1995), it was found that these taxa have not been so far reported from Odisha. Therefore, the present collection of two species of weedy amaranths count addition of species to the flora of Odisha. A detailed taxonomic description on morphology of two taxa along with field photographs, habitat/ ecology, germplasm collected and conserved were provided for easy identification and further utilization.

Both the species were found in wide range of habitats and grow luxuriantly in disturbed/ partly disturbed areas as weed in different landscapes such as waste lands, fallow fields, roadsides, field bunds and in unutilised farmers' fields in natural habitat and their occurrence were recorded at different locations of Odisha. A total of 42 germplasm accessions comprising *A. blitum* (10) and *A. dubius* (32) were recorded from different locations of phyto-geographical zones of Odisha. Both the species prefer direct sunlight and propagated through seeds and even from stem cuttings.

TAXONOMIC ACCOUNT

Amaranthus blitum L. (Fig. 1)

Amaranthus blitum L. Sp. Pl. 990 (1753); Prain in Bengal Plants 2:871 (1908); Haines Bot. Bihar & Orissa part v: 764 (1924); Giri *et al*. Mat. Arunanch. Prad. 2:301 (2008); *A. lividus* Hort. Petrop. ex Hook. f. in Fl. Brit. Ind. (J.D.Hooker) 4:721 (1885); *A. ascendens* Loisel. in Not. Fl. France 141 (1810); *A. tenuifolius* Roxb. In Fl. Ind. 3:602 (1832); *Amaranthus graecizans* var. *blitum* (L.) Kuntze in Revis. Gen. Pl. 2: 541 (1891); *Euxolus blitum* (L.) Gren. in Fl. Jurass. 2: 652 (1869); *Glomeraria blitum* (L.) Cav. in Elench. Pl. Horti Matr.: 16 (1803).

Annual herb, up to 30 cm height. Stem thin, procumbent or erect, grooved, simple or sometimes branched from base, glabrous, light green, the lower part of the stem being often ending in a terminal crown of leaves without spikes or panicle. Leaves small, lamina 1.5-5.0 × 1.0-3.5 cm, dotted, broadly ovate to orbicular, apex distinctly notched, retuse or emarginated to bi-lobed, often mucronate, margin entire or slightly undulate, long-petioled up to 6 cm, with 5-7 sec. nerves; base cuneate. Flower clusters axillary and terminal, cymose; terminal clusters erect spikes or complex thyrsoid cymes. Flowers minute; tepals 3, linear-oblong or lanceolate, muticous or apiculate, 1-1.5 mm long, hyaline; bracts and bracteoles oblong, shorter than tepals. Male flowers: radial; tepals 3, ovate, light green, stamens 3, slightly shorter than perianth; female flowers: radial, tepals 3, equal to subequal, oblong-lanceolate, elliptic, stigmas 3 or 2, falling off when utricles ripen. Utricle globose with short obtusely conical tip, membranous, indehiscent, slightly rugose to nearly smooth. ca. 3 mm. Seeds subglobose or broadly lenticular, smooth or slightly rugose, black or dark reddish brown, shiny, ca. 1.2 cm in diam. margins acute. Flowering and fruiting: November to January

Fig. 1. *Amaranthus blitum*: A. Natural occurrence on a wasteland at Banki block, Cuttack; B. Twigs showing morphological differences among *A. viridis*, *A. blitum* and *A. spinosus* (L-R); C. Seeds of *A. blitum*; D. Herbarium preserved at ICAR-NBPGR, Cuttack; E. Sale of sag at Nayagarh market; F. Consumption of cooked leafy vegetable by a rural man.

Distribution

The species is native to Mediterranean region and the range extends from Peru to Brazil, Bolivia, Chile, Paraguay and Argentina. Further, it is gradually naturalised in different parts of the globe. Some records were also available in different synonyms as *A. lividus*, in which it was reported to be cultivated or run wild in India in the Western Ghats and few states like Karnataka, Maharashtra, Goa, Tamil Nadu, Bihar, Uttar Pradesh, Haryana, Arunachal Pradesh, Jammu & Kashmir (Hooker, 1885; Saldanha, 1984; Almeida, 1990; Rao, 1986; Singh et al., 2001; Verma, 1993; Prain, 1908). It has been cultivated in Europe as a minor leafy vegetable crop, but now it is declining and its range is becoming progressively smaller. In many temperate countries (in particular in Europe), *A. blitum* persists mostly as an uncommon and sporadic weed in greenhouses, ornamental gardens, and flower beds. It flourishes in loamy soils with moderate rainfall, being a small plant, it can be challenging to distinguish from other closely related amaranth species, such as *A. viridis*.

Specimens examined and germplasm collected and conserved

Ten germplasm accessions of *A. blitum* were explored from different landscapes of Odisha and information on details of accession number, date of collection, habitat, frequency and sites of specimen collection were provided in Table 1. Further, the detail vegetative and floral characters of specimens were examined and identified.

Ethno-botanical uses

The tender shoots and leaves are consumed as green leafy vegetable in various culinary traditions. The chopped leaves can be eaten cooked like spinach and are often added to soups. The leaves are also mixed with corn or rice flour, fried and made into tasty cakes. It is used as animal food and a medicine, has environmental uses and for food.

Table 1. Specimens of *Amaranthus blitum* examined, seed germplasm collected and conserved

Sl. No	Coll. No.	IC. No.	Vernacular name	Date of collection	Source	Frequency	Site of collection			
							Village	Block	District	State
1	RCM/PKS/09	610680	Jungli khada	13.01.14	Wasteland	Occasional	Bilipada	Banki	Cuttack	Odisha
2	RCM/PKS/75	610742	Khunta sag	18.01.14	Disturbed wild	Occasional	Jamutia	Loisingha	Bolangir	Odisha
3	RCM/PKS/81	610748	Patar sag	18.01.14	Disturbed wild	Occasional	Chudapali	Bolangir	Bolangir	Odisha
4	RCM/PKS/84	610751	Bana khada	18.01.14	Wasteland	Occasional	Tusharbahal	Bolangir	Bolangir	Odisha
5	RCM/PKS/91	610757	Bana khada	19.01.14	Disturbed wild	Frequent	Barpadar	Patnagarh	Bolangir	Odisha
6	RCM/PKS/104	610769	Bana khada	20.01.14	Disturbed wild	Occasional	Tambipadar	Khaprakhol	Bolangir	Odisha
7	RCM/PKS/134	610796	Bana khada	22.01.14	Disturbed wild	Occasional	Kodasingha	Padampur	Bargarh	Odisha
8	RCM/PKS/148	610809	Jangli khada	23.01.14	Disturbed wild	Occasional	Jamurda	Bargarh	Bargarh	Odisha
9	RCM/PKS/149	610810	Jangli khada	23.01.14	Disturbed wild	Occasional	Jamurda	Bargarh	Bargarh	Odisha
10	RCM/PKS/154	610814	Nali khada	24.01.14	Disturbed wild	Occasional	Badakera	Anugul	Anugul	Odisha

Amaranthus dubius **Mart. ex Thell.** (Fig. 2)

A. dubius Mart. ex Thell. Fl. Adv. Montpellier 203 (1912); *Amaranthus dubius* Mart. in Pl. Hort. Erlang. 197 (1814), nom. nud; *Amaranthus dubius* var. *crassespicatus* Suess. in Mitt. Bot. Staatssamml. München 1: 73 (1951); *Amaranthus incomptus* Willd. in Enum. Pl. Hort. Berol., Suppl.: 64 (1814), nom. Nud; *Amaranthus hybridus* f. *acicularis* Suess. in Mitt. Bot. Staatssamml. München 1: 4 (1950); *Amaranthus spinosus* f. *inermis* Lauterb. & K. Schum. in Fl. Schutzgeb. Südsee 305 (1900).

Annual herb, up to 1m tall (sometimes 1.50 m). Stem erect, more or less stout, branched, glabrous or sparsely pubescent in distal parts, very often pinkish red, sometimes green. Leaves alternate, ovate or rhomboid-ovate to elliptic, 3-12 × 2-8 cm, petiole up to 7 cm, petiole of proximal leaves equalling or longer than blade, becoming shorter distally; base cuneate, margins entire, apex acute to faintly obtuse, mucronate, glabrous above, pubescent on nerves beneath; Inflorescences in terminal panicles and axillary spikes; panicles erect or very often drooping, the terminal one up to 20 cm long, green in young and brownish in ripe, dense; bracts linear to lanceolate, ca 2mm, shorter than tepals, apex spinescent, greenish-white. Pistillate flowers: radial, tepals 5, oblong-spathulate, not clawed, 1.5-2.5 mm, apex pointed, shortly mucronate, yellowish, ovary 1-celled, style branches spreading, stigmas 3. Staminate flowers: radial, tepals 5, equal or subequal; stamens 5, ca 2 mm long; clustered at tips of inflorescence branches, sometimes gathered in proximal glomerules. Utricles ovoid to subglobose or urceolate, 1.5-2 mm, slightly shorter than tepals, beaked, smooth or wrinkled, dehiscence circumscissile, 1-seeded. Seeds dark reddish brown to black, subglobose or lenticular, 0.8-1 mm diameter, shiny, smooth. Flowering and fruiting: December to January.

Fig. 2. *Amaranthus dubius*: A-B. Natural occurrence at Khandapada block, Nayagarh and Dharmagarh block, Kalahandi districts; C. Leaves; D. Apical twigs; E. Inflorescences in terminal panicles; F. Herbarium preserved at ICAR-NBPGR, Cuttack; G. Seeds; H. A tribal man collects leaves for consumption .

Distribution

The species is native to South America, Mexico and West Indies, however, it is widely spread throughout the world and naturalised in tropical and subtropical regions of United States, Africa, Asia, Australia and the Pacific (CABI, 2019). It was reported to be run wild and domesticated in several parts of India from the states of Maharashtra, Tamil Nadu, Kerala, Andhra Pradesh, Madhya Pradesh, Himachal Pradesh etc. (Khanna et al., 2001).

Specimens examined and germplasms collected and conserved

A total of 32 germplasm accessions of *A. dubius* were collected from different landscapes of Odisha and passport information on details of accession number, date of collection, habitat, frequency and sites of specimen collection were provided in Table 2. The morphological characters of specimens were examined and identified.

Table 2. Specimens of *Amaranthus dubius* examined, seed germplasm collected and conserved

Sl. No	Coll. No.	IC. No.	Vernacular name	Date of collection	Source	Frequency	Site of collection			
							Village	Block	District	State
1	RCM/PKS/02	610673	Dhala khada	13.01.14	Farmer's field	Frequent	Bramanigan	Baranga	Cuttack	Odisha
2	RCM/PKS/05	610676	Khada	13.01.14	Farmer's field	Occasional	Kainmumdi	Baranga	Cuttack	Odisha
3	RCM/PKS/21	610691	Nali khada	14.01.14	Farmer's field	Frequent	Talasahi	Khandapada	Nayagarh	Odisha
4	RCM/PKS/25	610695	Dhala khada	14.01.14	Farmer's field	Occasional	Gopinathpur	Khandapada	Nayagarh	Odisha
5	RCM/PKS/29	610698	Dhala khada	15.01.14	Farmer's field	Frequent	Bhatasahi	Nayagarh	Nayagarh	Odisha
6	RCM/PKS/33	610701	Nali khada	15.01.14	Farmer's field	Frequent	Patharpunja	Daspalla	Nayagarh	Odisha
7	RCM/PKS/34	610702	Dhala khada	15.01.14	Farmer's field	Frequent	Patharpunja	Daspalla	Nayagarh	Odisha
8	RCM/PKS/39	610707	Nali khada	15.01.14	Farmer's field	Frequent	Patharpunja	Daspalla	Nayagarh	Odisha
9	RCM/PKS/117	610780	Khada sag	21.01.14	Farmer's field	Occasional	Munekel	Paikamal	Bargarh	Odisha
10	RCM/PKS/121	610784	Khada sag	22.01.14	Farmer's field	Occasional	Barhiapalli	Padampur	Bargarh	Odisha
11	RCM/PKS/124	610787	Khada sag	22.01.14	Farmer's store	Occasional	Amamunda	Padampur	Bargarh	Odisha
12	RCM/PKS/127	610789	Desi khada	22.01.14	Farmer's field	Frequent	Nuapalli	Padampur	Bargarh	Odisha
13	RCM/PKS/128	610790	Gachha khada	22.01.14	Farmer's field	Occasional	Kodasingha	Padampur	Bargarh	Odisha
14	RCM/PKS/135	610797	Khada sag	23.01.14	Farmer's store	Occasional	Nileswar	Bargarh	Bargarh	Odisha
15	RCM/PKS/141	610803	Chilkani khada	23.01.14	Farmer's field	Occasional	San Dumerpalli	Bargarh	Bargarh	Odisha
16	RCM/PKS/144	610805	Agala khada	23.01.14	Farmer's field	Frequent	Patharla	Bargarh	Bargarh	Odisha
17	RCM/MRS/46	641717	Nali banakhada	18.12.20	Wasteland	Occassional	Sugar factory	Aska	Ganjam	Odisha
18	RCM/MRS/50	641718	Nali khada	18.12.20	Wasteland	Occassional	Katakala	Buguda	Ganjam	Odisha
19	RCM/SS/21	641743	Khunta saga	04.03.21	Disturbed wild	Occassional	Parukunda	Barkote	Deogarh	Odisha

20	RCM/SS/33	641751	Khunta saga	05.03.21	Disturbed wild	Occassional	Machurinali	Banei	Sundargarh	Odisha
21	RCM/SS/35	641753	Khunta saga	05.03.21	Fallow land	Occassional	Kaliposh	Lahunipada	Sundargarh	Odisha
22	RCM/SS/73	641777	Khunta saga	08.03.21	Fallow land	Occassional	Suruguda	Lephripada	Sundargarh	Odisha
23	RCM/SS/76	641780	Khunta saga	09.03.21	Wasteland	Occassional	Nakshapalli	Maneswar	Sambalpur	Odisha
24	RCM/BV/ PK/24	649114	Khunta saga	09.12.22	Disturbed wild	Occasional	Kendrikela	Bonai Ghosh	Sundargarh	Odisha
25	RCM/ MKM/25/14	658087	Janglikhada	16.01.25	Disturbed wild	Occasional	Dhumabhata	Belparha	Balangir	Odisha
26	RCM/ MKM/25/20	658088	Janglikhada	17.01.25	Disturbed wild	Occasional	Phasad	Puintala	Balangir	Odisha
27	RCM/ MKM/25/75	658093	Patarsag	21.01.25	Wasteland	Occasional	Bhoirajpur	Khariar	Nuapada	Odisha
28	RCM/ MKM/25/83	658095	Patarsag	22.01.25	Wasteland	Occasional	Gudguda	Titlagarh	Balangir	Odisha
29	RCM/ MKM/25/98	658098	Patarsag	23.01.25	Wasteland	Frequent	Kendubahali	Narla	Kalahandi	Odisha
30	RCM/ MKM/25/113	658099	Khunta sag	25.01.25	Wasteland	Occasional	Badabasula	Dharmagarh	Kalahandi	Odisha
31	RCM/ MKM/25/117	658101	Patarsag	25.01.25	Disturbed wild	Occasional	Pandigan	Kalampur	Kalahandi	Odisha
32	RCM/ MKM/25/138	658102	Patarsag	28.01.25	Disturbed wild	Occasional	Rayagada	Rayagada	Rayagada	Odisha

Ethno-botanical uses

The dark green tender leaves are plucked and cooked as green leafy vegetable with brinjal, pumpkin and tomato and consumed as curry or *bhaji* during the day meal. The leaves are also mixed with corn or rice flour and onion, fried and taken as delicious cakes. It is also used as cattle food and medicine. The seeds are fried and consumed by the rural poor people.

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Evaluation of seed composition of *Abelmoschus moschatus* Medik. (*muskdana*), an aromatic medicinal plant from Eastern India

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ABSTRACT

Abelmoschus moschatus Medik., commonly known as *muskdana* or *ambrette,* an important aromatic and medicinal plant of family Malvaceae, is native to India. It is used traditionally in the treatment of various health ailments across the world. The aromatic seeds of this plant are aphrodisiac, ophthalmic, cardio-tonic, antispasmodic and used in the treatment of intestinal complaints. The plant has been extensively studied by various workers for its biological activities and therapeutic potential. In the present paper, the species was explored from Odisha and West Bengal, morphologically described and conserved in the National Gene Bank. The aromatic seeds of *A. moschatus* were analysed to study the seed composition viz. moisture, mucilage, extractive yield, total sugars, crude oil, phenols, flavonoids, tannins and ash content. It is valued for its scented seeds which contained essential oil content of 0.20 to 0.28% with a strong musky and brandy odour. Seed fixed oil is primarily composed of unsaturated essential fatty acids, such as linoleic and oleic acids which are beneficiary for human health and diet. *A.moschatus* may therefore, be a good candidate for functional foods, cosmetics as well as pharmaceutics.

Key words: *Abelmoschus moschatus,* essential oil, *muskdana,* phyto-chemical, seed germplasm

INTRODUCTION

Abelmoschus moschatus (family: Malvaceae), popularly known as *ambrette* or *muskdana*, is an important aromatic and medicinal plant of India. The plant is widely cultivated in tropical countries for their musk-scented seeds useful in perfumery and medicine (Anonymous, 1959). It is mainly distributed in South-East Asia viz. China, Bangladesh, Indo-Chinese peninsula, West Indies, Indonesia, Malaysia, and Thailand. Plant is valued for its scented seeds yielding ambrette oil of commerce, which finds application both in flavour and fragrance formulations apart from its potential use in traditional medicines (Chopra et al., 2005). The seeds of *Abelmoschus moschatus* yield an essential oil with a strong musky and brandy odour due to the presence of ambrettolide, a macro-cyclic lactone in the seed coat (Du et al., 2008; Nautiyal and Tiwari, 2011). The other major components are farnesol and farnesyl esters, acyclic aliphatic esters and terpenes (Cravo et al., 1992). The seeds are used for various therapeutic purposes which include treating headache, cramps, muscular aches and pains, depression and other nervous complaints. Ambrette seeds are exported to China, Germany, France, Netherlands, Nepal, Spain, Belgium, UAE, Switzerland, Singapore and United Kingdom to the extent of about 116 quintals in a year because of its diversified uses. This species is extremely important from the therapeutic point of view. Because of their effectiveness against “kapha” and “vata,” intestinal complaints, stomachic and heart diseases, the aromatic seeds are highly valued as medicines. Ambrette seeds are considered as cardio-tonic, digestive, carminative, diuretic and deodorant, apart from possessing antiseptic, anti-spasmodic, and anti-vomiting properties (Pawar et al., 2017). The oil extracted from this crop has a great national and international demand. This increasing demand has motivated the farmers to cultivate this important medicinal crop fairly in a large scale.

The species is native to India and found in almost all states, especially in West Bengal, Bihar, Uttar Pradesh, Odisha and Andaman and Nicobar Islands. It is widely distributed and cultivated as an oil seed crop in Bangladesh, China, Indo-Chinese peninsula, Thailand, Malaya peninsula, Indonesia, Fiji islands. It is also grown in gardens for its ornamental potential. Sometimes, it is found as an escape in wastelands, river banks, along railway tracks and roadsides. Every part of this medicinal plant is used in one or in the other way. Despite substantial demand in the cosmetics industry, research efforts aimed to uncover the yield potential of Indian *muskdana* remain unknown or less-known, requiring attention to introduce new cultivars into commercial farming. The objective of this study was to explore, document, conserve and to evaluate the phyto-chemical composition of *muskdana* seeds, collected from Odisha and West Bengal.

MATERIALS AND METHODS

Plant material

While conducting the exploration mission for germplasm collection of wild *Abelmoschus* and other crops, the authors observed the occurrence of *Abelmoschus moschatus,* a wild scented-seed okra, locally called as "*Kasturi Bhendi* (Odia) and *Kal-kastari* or *mushak-dhana* (Bengali)", in disturbed sites on wastelands and fallow lands in parts of Odisha(Fig. 1A) and West Bengal. The seed germplasm samples of plant species free from insect damage and disease symptoms and without any mechanical injury were collected from the collection site in ripe fruiting stage and conserved in the National Gene Bank, ICAR-NBPGR, New Delhi for long term storage. The ethno-botanical/economic uses collected from local tribes and relevant literatures were documented. The plant specimens bearing vegetative and floral parts were collected and deposited in the herbarium of the centre along with one set at the National Herbarium of Cultivated Plants (NHCP), ICAR-NBPGR, New Delhi.

Extraction of essential oil

The seeds collected during the exploration were multiplied and the germplasm were maintained at the experimental plot, ICAR-NBPGR, Cuttack. Freshly harvested seeds of *A. moschatus* (500 g) without any mechanical injury were assembled, shade dried and stored for further chemical analysis. Dried seeds were hydro-distilled in a Clevenger apparatus for 4 hours, for extraction of the essential oil. The oils were measured, collected in a glass vial and dehydrated by adding anhydrous $Na_2SO_4$and stored in a glass vial at 4 ºC temperature until further analysis.

Proximate composition analysis

Fifty-gram of dry *muskdana* seeds were homogenized using a stainless-steel mixer grinder. Fine powder was prepared by grinding and then sieved using a test sieve of ASTM 35 to ensure homogeneity for further investigation. *Muskdana* samples were analysed in duplicates following official standard methods (AOAC, 2016) and the results are expressed as the mean of replications. Proximate seed composition analysis was performed as follows: moisture content was obtained by drying 2 g of homogenized seed flour in the hot air oven at 80° C for 2 hr and repeat drying for 2 h, until constant dry weight was obtained. Ash content was obtained by incineration of flour sample in a muffle furnace at 450° C for 5 hr; crude fat was extracted using non-polar solvent petroleum ether (40-60° C) in a Soxhlet extractor for 24 h.

Fatty acid profiling of seed oil

Muskdana seed powder was used to extract crude oil using a solvent mixture of chloroform, hexane, and methanol (8:5:2 *v*/*v*/*v*) in 10 ml. The resulting extracts were dried for 30 min. at 60°C in nitrogen gas and methyl esters of oil samples were prepared (Neff et al., 1994). Fatty acid analyses were done on Agilent Gas Chromatograph (Model 7890A) with a flame ionization detector (FID), 5975C GC/MS and HP-5MS capillary column (30 m length × 0.25 mm internal diameter; 0.25 µm film coating). Helium was used as a carrier gas (1mL/min). Temperatures for the injector and detector were kept at 260°C and 275°C, respectively. The oven temperature was designed to rise from 175ºC with a hold time of 5 min to 250ºC at a rate of 5 ºC/min with final hold time of 10 min. Fatty acid methyl esters peaks were identified by comparing the retention times of fatty acid peaks with those of FAMES standard mixture done running under similar separation circumstances. The individual fatty acids (%) is expressed as percent peak area relative to total peak area. All analyses were performed in duplicates and results were expressed as mean ± standard deviation (SD).

Estimation of phyto-constituents

About 500 mg of seed powder was extracted three times in hot 80% ethanol and centrifuged at 10,000 g for 10minutes, and supernatants were pooled, and volume was made up to 20ml. Ethanolic extract was dried on a boiling water bath and the residue was re-suspended in 20ml for further analysis by standard spectrophotometric methods (AOAC, 2016). This extract was used for estimation of total sugars by anthrone reagent method (Roe 1955), total phenols (Singleton et al., 1999), total flavonoids (Chang et al., 2002) and total tannins (Price et al., 1978) respectively.

RESULTS AND DISCUSSION

The plant species was noticed in wild/ naturalized state in disturbed habitats on the wastelands, fallow fields and river banks viz. Tangi-Chowdwar block, Cuttack district; Bhandaripokhari block, Bhadrak district; Indupur, Kendrapada district; Nimapada block, Puri district; Karlapat, Kalahandi district of Odisha and Barrackpore and Sagar islands of West Bengal. The species distribution was very rare, found in isolated moist habitats and the germplasm status was tending to decline rapidly due to habitat loss. The morphological features of vegetative and floral parts were examined and the detailed taxonomic characters were described (Fig. 1).

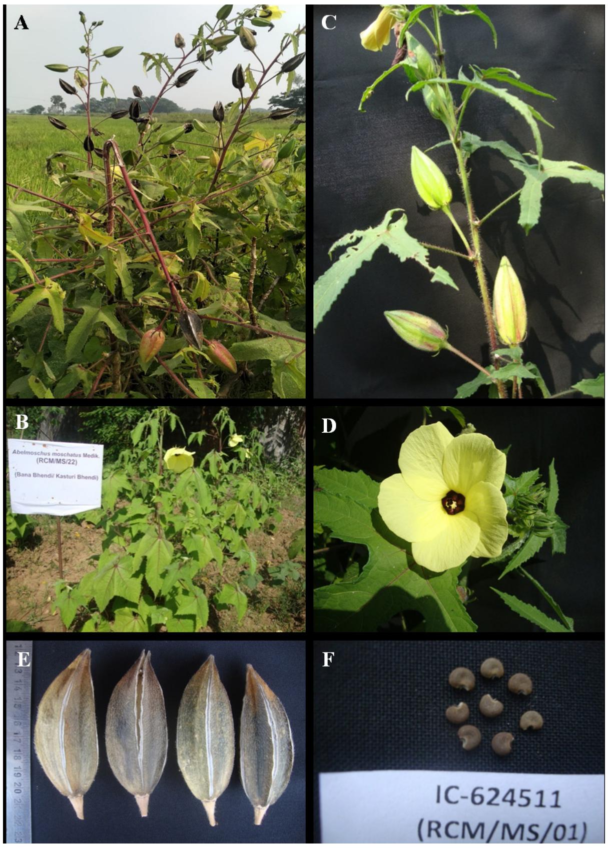

Fig. 1. *Abelmoschus moschatus*: A. Natural occurrence in Bhadrak district, Odisha; B. Maintained at ICAR-NBPGR, Cuttack; C. Twig bearing flowers and fruits; D. Flower; E. Ripe fruits; F. Seeds

***Abelmoschus moschatus* Medik.**

Abelmoschus moschatus Medik. Malv. 46. 1787; Borssum, Blumea 14:91. 1966; Paul & Nayar, Fasc. FI. India 19:77.t. 16. 1988. *Hibiscus abelmoschus* L. Sp.Pl. 696. 1753; Mast. in Hook. f. Fl. Brit. India 1:342. 1874; Gamble, FI. Madras 1:97(69). 1915; Haines, Bot. Bihar & Orissa 1:65 (67). 1921.

Vernacular name

Kasturi Bhendi, Bano bhendi (Odia); *Muskdana* (Hindi, Beng.); *Kasturi benda* (T); Musk mallow, Ambrette, vegetable musk (Eng.); *Latakasturikam* (Sans.); *Kasturibende* (Kan.); *Gorukhia-korai* (Assam).

Species morphological description

Erect undershrub upto 2.5 m high; stem and branches dense hirsute, hairs usually long, stiff, not bristly, retrorse, 3-4 mm long; nodes deep purple spotted. Leaves variable, mostly orbicular, 8-25 cm across, usually cordate, angular or 3-7-lobed or-parted, palmatifid or palmatisect, lobes coarsely serrate, of the upper leaves usually narrower, basal part of lobe mid-vein deep purple, both surfaces hairy, lower surface with scattered stellate hairs; petiole 3-20 cm; stipules linear, 8-20 mm, hairy. Flowers solitary, deep yellow with dark purple centre, 8-12 cm across; pedicels 3-5 cm, upto 9 cm in fruit, puberulent. Epicalyx segments 7-10, linear, free, 10-30 mm long, hirsute, caducous. Calyx 2.5-3.7 cm long, tomentose outside, sericeous, glabrous inside, purple veined, apex acute, 3-lobed. Corolla thinly veined. Staminal column thick, 1.5-2.5 cm long, stamens dense, deep yellow; stigma 5-lobed, dark-purple. Capsule ovoid to oblong or lanceolate, 5-8 cm × 2-3 cm, 5-angled, with a short beak, densely soft strigulose. Dehiscing laterally, rostrum ca 1 cm long. Seeds brown to blackish-brown, reniform, 3-4 mm. across, glabrous, minutely warty in concentric rings, musk-scented; hilum 0.2 × 0.1 cm, ovate. FIowering: October-November, Fruiting. November- January.

Germplasm collected and conserved

i) Site 1: India, state: West Bengal, district: Barrackpore, block: Barrackpore, nearby village: Nilganj, *R.C.Misra*, HS number 325 (Herbarium of ICAR-NBPGR Base Centre, Cuttack), dated 05.04.2017; seed germplasm acc. no. IC624511 (Collection no. : RCM/MS/01); source: disturbed wild, fallow land; frequency: rare; 22° 46' N lat. 88° 26' E long. Local name: *Muskdana*.

ii) Site 2: India, state: West Bengal, district: South 24 Parganas, block: Namkhana, nearby village: Biswa Laxmipur, Sagar islands; *R.C.Misra,*HS number 326 (Herbarium of ICAR-NBPGR Base Centre, Cuttack), dated 08.04.2017; seed germplasm acc. no. IC624513 (Collection no. : RCM/MS/22); source: wild, partlydisturbed, weedy, wasteland; frequency: rare; 21° 50' N lat. 88° 14' E long.

iii) Site 3: India, state: Odisha, district: Cuttack, block: Tangi-Chowdwar, nearby village: Tarota-Nirgundi, dated 27.11.2024; seed germplasm accession no. IC-655314 (Collection no. : RCM/PK/24/02); source: disturbed wild, frequency: rare; 20° 33' N lat. 85° 58' E long. Local name: *Kasturi Bhendi*.

iv) Site 4: India, state: Odisha, district: Bhadrak, block: Bhandaripokhari, nearby village: Puripada, dated 27.11.2024; seed germplasm accession no. IC-655316 (collection no. : RCM/PK/24/04); source: wild, partly disturbed; frequency: rare; 20° 56' N lat. 86° 19' E long. Local name: *Kasturi Bhendi*.

Economic uses

Seeds are used as a stimulant, tonic and carminative. Essential oil obtained from the seeds is used in high grade perfumery and spiritual purposes. Tender leaves and young shoots are consumed in preparing scented soups. The bark yields a good quality fibre. The species is also cultivated in gardens as ornamental plant for its showy flowers. Seeds are effective aphrodisiac and antispasmodic, and used in tonics. They check vomiting and are useful in treating intestinal disorders, urinary discharge, nervous disorders, hysteria, skin diseases etc. The mucilaginous seeds are emollients and demulcents. Flower infusion is contraceptive. Different parts of the plant have uses in traditional and complementary medicine, not all of which have been scientifically proven. It is used externally to relieve spasms of the digestive tract, cramp, poor circulation and aching joints. It is also considered an insecticide and an aphrodisiac. The roots, leaves and seeds of ambrette are considered valuable traditional medicines.

Proximate seed composition

The analysis of seeds of *A. moschatus* revealed the nutritional and anti-nutritional components as presented in Table 1. The seed moisture content ranged between 10.34 and 10.51% on dry weight and 100 seed weight was found 1.22-1.25g. *Abelmoschus* species contains mucilage (11.50-14.64%) which has several food and medicinal applications. It is useful in cleaning the sugar cane juice in jaggery preparation. Isolation and identification of many compounds from wild species proved to have diverse medicinal properties along with extraordinary nutritional potential.

Extractive yield obtained from seeds was 19.59-20.97% in methanol which was found best solvent for extraction purpose.

Table 1. Chemical composition of seeds of *A. moschatus*

Quality trait	Mean ± SD*	Range
100 seed weight (g)	1.22 ± 0.03	1.22 - 1.25
Moisture (%)	10.42 ± 0.12	10.34 - 10.51
Mucilage (%)	13.08 ± 2.23	11.50 - 14.65
Extractive yield (%)	20.28 ± 0.98	19.59 - 20.97
Essential oil (%)	0.24 ± 0.06	0.20 - 0.28
Total phenols (mg g^{-1})	8.44 ± 0.63	7.99 - 8.88
Total flavonoids (mg g^{-1})	16.88 ± 1.02	16.16 - 17.60
Tannins (%)	6.50 ± 1.16	5.68 - 7.32
Total sugars (%)	4.09 ± 0.17	3.97 - 4.21
Crude oil (%)	19.30 ± 0.52	18.93 - 19.66
Ash (%)	4.57 ± 0.45	- 4.89

*SD (Standard Deviation)

The ambrette seeds showed presence of essential oil content of 0.20-0.28% with mean value of 0.24 ± 0.06% (v/w) on hydro-distillation. Oil was pale yellow coloured with a characteristic musk-like odour (Pandey et al., 2025).The major compounds noted were farnesyl acetate, farnesol and (Z)-Oxacycloheptadec-8-en-2-one (ambrettolide). The characteristic musk-like odour of the *muskdana* oil is attributed to the presence of a ketone, ambrettolide, which is lactone of ambrettolic acid (16-hydroxy-7-hexadecenoic acid). The seeds are the source of ambrette, an aromatic oil, used in perfumery (Rout et al., 2004; Arokiyaraj et al., 2014). Ambrette oil is used in luxury perfumery, cosmetics and as an additive in the preparation of some kinds of chewing tobacco, baked products, sweets, alcoholic (e.g. vermouth and bitters) and non-alcoholic drinks. India, Colombia, Ecuador and Martinique are the main producers of ambrette oil, worldwide. In India, the area cultivated with *muskdana* is gradually increasing. The ash content of dry seed powder ranged from 4.25 to 4.89%, indicating presence of more minerals in this species. The ash content is considered a measure of the mineral content in the seeds, indicating they are a good source of essential minerals. These minerals play major roles in the cell repair and maintenance, as well as regulation of the human body. The seeds were measured the total crude fat content ranging from 18.93 to 19.66% and total sugars from 3.97 to 4.21%.Total phenols content of *A. moschatus* seeds varied from 7.99 to 8.88 mg/g^{-1} gallic acid equivalent(GAE). Phenolic compounds serve as the key roles as primary antioxidants or free radical scavengers. The antioxidant activity of the phenolic compounds is mainly due to their redox properties, which can play an important role in absorbing and neutralizing free radicals, quenching singlet and triplet oxygen or decomposing peroxides (Mishra et al., 2020). It has been suggested that poly-phenolic compounds impart anti-mutagenic and anti-carcinogenic properties on daily consumption of ~1.0 g of diet rich in vegetables and fruits. Total flavonoid content ranged between 16.16 and 17.60 mg quercetin equivalent/g DW and total tannin content ranged from 5.68 to 7.32%. The seed composition in present study was found close to earlier reports (Pawar et al., 2017).

Fatty acid profiling

A. moschatus seeds contain a significant amount of fixed oil content varying from 18.93 to 19.66%. Evaluation of quality of crude oils, fatty acid composition has a special significance due to the fact that some fatty acids cause hyper-lipidemic and cholestermic effects in the body. Saturated fatty acids have a more hyper-lipidemic effect than the unsaturated fatty acids. Fatty acid composition of *A. moschatus* seed oil by gas chromatography and flame ionization (GC/FID) showed presence of nine major fatty acids (Table 2). The relative percentage of fatty acids showed presence of four major fatty acids in seed oil namely linoleic (C18:2), oleic (C18:1), palmitic (C16:0) and stearic (C18:0) acid (Fig. 2). Fatty acid profile revealed presence of higher amounts of unsaturated fatty acids of oleic acid (41.90-52.18%) and linoleic acid (19.59-22.16%) considered to be nutritionally important. Linoleic acid is the important unsaturated essential fatty acids required for growth, physiological functions and maintenance of body. Oleic acid content estimated in the present study was comparatively higher than the other species of *Abelmoschus esculentus* (Jarret et al., 2011). Among saturated fatty acids palmitic acid (20.21-20.43%) and stearic acids (3.42-3.85%) were found in predominant amounts. The total polyunsaturated fatty acids (PUFAs) of the seed oil ranged from 66.03–73.07%, while total saturated fatty acids (SFAs) had a very low level content (24.83-26.06%). The oleic acid/ linoleic acid (O/L) ratio was 1.98 used as stability index. Fatty acids are used in cosmetics industry because of skin care properties such as anti-inflammatory, acne-reduction and moisture retention properties and play important role in lowering of blood pressure, relaxation of coronary arteries, and inhibition of platelet aggregation. Lipid and fatty acid composition in foods, contributes to their physical, nutritional, and sensory qualities.

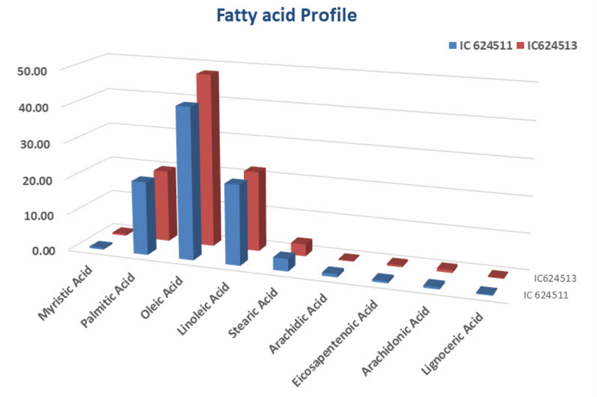

Fig. 2. Relative fatty acid (%) in seed crude oil of *Abelmoschus moschatus* genotypes

Table 2. Fatty acid composition (%) of crude oil of *A. moschatus* seeds

Fatty Acid	Class	IC624513		IC64511		Mean	Range
		R1#	R2#	R1#	R2#		
Myristic acid (C14:0)	SFA	0.51	0.54	0.52	0.47	0.50	0.47 - 0.54
Palmitic acid (C16:0)	SFA	20.21	21.43	21.43	20.32	20.87	20.21 - 21.43
Oleic acid (C18:1)	UFA	51.68	52.18	52.18	41.90	47.04	41.90 - 52.18
Linoleic acid (C18:2)	UFA	20.17	19.59	19.59	22.16	20.37	19.59 - 22.16
Stearic acid (C18:0)	SFA	3.79	3.85	3.85	3.42	3.63	3.42 - 3.85
Arachidic acid (C20:0)	UFA	0.27	0.13	0.13	0.83	0.48	0.13 - 0.83
Eicosapentaenoic acid (C20:5)	UFA	0.63	0.53	0.53	0.56	0.55	0.53 - 0.63
Arachidonic acid (C20:4)	UFA	0.32	0.24	0.24	0.58	0.41	0.24 - 0.58
Lignoceric acid (C24:0)	SFA	0.23	0.23	0.26	1.60	0.91	0.23 - 1.60
*SFA (%)		24.83	25.78	26.06	25.81	25.91	24.83 - 26.06
**UFA (%)		73.07	72.67	72.67	66.03	68.85	66.03 - 73.07
TOTAL (%)		97.90	98.45	98.73	91.84	94.76	91.84 - 98.73

*Saturated Fatty Acid (SFA); **Unsaturated Fatty acid (UFA)

#R1 (Year 2020); R2 (Year 2021)

CONCLUSION

The ambrette seed oil has a promising value for fragrance and fixative purposes. Based on the results of this study, it is revealed that ambrette can also produce good quality essential oil. The present study indicated that *A. moschatus* contains considerable amount of total polyphenols and flavonoids and exhibited good antioxidant activity. The antioxidant and biological activities might be due to the synergistic actions of bioactive compounds present in the seeds. However, it is still unclear that which components are playing vital roles for these activities. Therefore, further studies are still needed to elucidate mechanistic way, how the plant contributes to these properties.

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Archaeological evidence of prehistoric grassland systems in the Southern Aravallis, Rajasthan, India

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ABSTRACT

The cup like structures that have been excavated by the ancient men on the rocks are called 'cup marks' or 'Cupules'. The cupules are present at many places in the Aravallis, from its northern part to southern and a good numbers are seen near Jhalo-Ka-Kalwana (Gogunda tehsil) in southern Aravallis in Udaipur district. The confirmed age of the cupules seen in Jhalo-Ka-Kalwana area is not exactly known. These cupules seem contemporary with the primary grasslands of the area. It has been predicted that the cupules of Jhalo-Ka-Kalwana area may be date back to 10,000 to 20,000 years. It indicates that the grasslands confined around Jhalo-Ka-Kalwana on certain piedmonts may be 10,000 years old or in their existence. The authors invite further studies to establish the age of the grasslands through historical evidence.

Key words: Gogunda tehsil, grassland, prehistorical status, Rajasthan, Southern Aravallis

INTRODUCTION

Rajasthan is the largest state of Indian Union which is situated towards the North Western part of the country between 23^0 3' and $30^0$12' N latitude and 69^0 30' and 78 17' E longitude (Shetty and Singh, 1987). The Aravallis are an important feature of the state which is a folded and residual mountain chain which is bisecting the state into two unequal parts. This mountain chain is present across four states of the country namely, Gujarat, Rajasthan, Haryana and Delhi. The Aravallis are well known for their forests and grasslands. As per Champion and Seth (1968) the grasslands of Aravallis in Rajasthan are $5/DS_4$ (Dry grassland), which is a degraded stage of Dry Deciduous Forests.

Rajasthan is rich in grass flora. More than 300 species of grasses are known from the geographical limits of Rajasthan (Shetty and Singh, 1993; Kelkar, 2009; Kotiya et al., 2020). Dabadghao and Shankarnarayan (1973) have classified grasslands of India into five types namely, *Sehima-Dichanthium, Dichanthium-Cenchrus-Lasiurus,Phragmites-Saccharum-Imperata, Themeda-Arundinella* and Temperate alpine. Rajasthan possesses first two types of grasslands. The remaining types are not present in Rajasthan as they are mainly confined to Himalayan region of North and North Eastern part of India. The *Dichanthium-Cenchrus-Lasiurus* grassland is mainly confined to Thar desert, west of the Aravallis while *Sehima-Dichanthium* grass land is confined to the Aravallis and east of the Aravallis up to Hadoti zone of the state.

A considerable amount of scientific literature is available on the grasslands of Rajasthan but no literature is available about the age of the grasslands, how old they are? Answer of this fact is missing in the scientific literature of forestry and botany. Though, records of the recent past of the grasslands are available but prehistoric information are missing.

MATERIALS AND METHODS

Many sites of archeological importance like Panchmadhi and Gandhisagar Wildlife Sanctuaries in Madhya Pradesh; Shilakhadi and Mangar Bani area in Faridabad district in Haryana; Konkan area in Maharashtra; Bijoliya and Bundi area in Rajasthan were surveyed. Rock arts of prehistoric human are available here and there in these sites. Scientific literature related to these sites were scanned to draw the information about status of prehistoric grasslands. Shilakhadi, Mangar and Gandhisagar are present close to Rajasthan. Probably, to and fro movement of ancient men was possible among these sites during the prehistoric time.

Our main focus was on the Gogunda tehsil of Udaipur district in southern Aravallis. Hence, grasslands of the area were studied extensively. Rock arts were also searched in the caves, overhang cliffs and sheltered places. Help of local tribals was taken to probe the remote areas. First author, being a retired forest officer, used his contacts and skill to explore the potential sites in the deeper forest areas. Wherever a rock art was traced, the status and composition of the grassland around the site were studied. GPS was used to record the co-ordinates of the sites and photographic evidences were taken.

Observations

Forested area, grasslands and sacred groves were explored extensively. Forest patches near many sacred sites are still in good condition and available without or with least disturbances and damages. These can be considered as "Reference Forests" to compare with old primary forests and today's secondary forests.

While wandering in the forests and grasslands, the authors found rock art at many places in Gogunda tehsil in Udaipur district. This area is confined to southern Aravallis. Though, we find rock arts at many places but we focused on Jhalo-Ka-Kalwana village landscape (Fig. 1-4). Details of the rock art of the village along with related information is given below in Table 1. The rock arts were carefully examined and the details are shown in Table 2.

Table 1. Rock art site locations at Jhalo-Ka-Kalwana village, Gogunda tehsil, Udaipur district

Location No.	Nearest village	Co-ordinates of rock art site	Types of rock art	Vegetation type and spread in surrounding landscape	
				vegetation type	Appx. area (in ha.)
1	Jhalo-Ka-Kalwana	24.960213 N, 73.446622 E	Cupules (cup marks) and carved sloth bear pugmark	Grassland	100
2	Jhalo-Ka-Kalwana	24.960212 N, 73.443802 E	Cup marks	Grassland	Continuation of site 1
3	Jhalo-Ka-Kalwana	24.958081 N, 73.442056E	Cup marks	Grassland	Continuation of site 1
4	Jhalo-Ka-Kalwana	24.960212 N, 73.443802 E	Cup marks	Grassland	Continuation of site 1

Table 2. Details of rock arts seen in Jhalo-Ka-Kalwana village

Location No.	Type of surface of the rock on which art is present	Comparison of surface of the rock and surrounding terrain	Visibility of the rock having art	Location of the rock having art
All locations viz., 1,2,3,4 (as given in Table 1)	Flat exposed rock on the ground. Primary surface is rough	Rock surface and surrounding surfaces having more or less same level	Clearly visible from all directions	Present on a piedmont

Fig. 1. A flat rock having depiction of sloth bear pug marks and cupules

Fig. 2. Enlarged pug mark of the sloth bear

Fig. 3. Site of rock art depicting cupules (cup marks)

Fig. 4. Closeup of a cup mark

RESULTS AND DISCUSSION

During the present study, rock art of prehistoric period was found at Jhalo-Ka-Kalwana village in Gogunda tehsil of Udaipur district. The study area is a hilly zone and many parallel mountain chains run broadly in South to North direction. The study site is a piedmont of low height, occupied by the rolling grassland which is 5/DS_4 dry grassland (Champion and Seth, 1968). According to Dabadghao and Shankarnarayan (1973) it is *Dichanthium – Sehima* grassland type. A high mountain called 'Jarga Parvat (Jarga hills)' is present nearly one kilometer away towards eastern side of the study area which possess the second highest peak of Rajasthan after Mount Abu hilly zone. Dense forest cover is present throughout the whole Jarga hills. The forest type on the Jarga hills is mainly 5A-Southern tropical dry deciduous forest (Champion and Seth, 1968). The river Banas flow near the Jarga hills.

During the survey of the forest and grassland area under study, a thought came into the mind of the authors, whether the grassland of Jhalo-Ka-Kalwana village landscape is primary or secondary in its origin ? When a forest is destroyed, grasses start their succession and in due course of time, a grassland comes into existence. Such grassland is called a secondary grassland. If a grassland is historic or prehistoric in origin, it is called a primary grassland. Thus, the question arises; whether the above study area grasslands are primary grasslands or secondary grasslands? It needs further studies.

Rock art seen at Jhalo-Ka-Kalwana area, provided an important clue about the nature of the local grassland. Rock art of location 1 is very interesting. Here, a flat rock having depiction of sloth bear *(Melursus ursinus)* pugmarks and more than one dozen cupules is worth seeing. The rock is situated towards the top zone of a piedmont. Extensive grasslands are present on different piedmonts of varying heights around this location. Presence of these cupules (cup marks) and sloth bear pugmarks on the flat rocks at location 1,2,3 and 4 indicate that today's visible grasslands of the area are of primary nature. They are not the result of modern destruction of the forest cover but their presence is prehistoric. It is evident from two reasons:

The cup marks are present on the primary surface of the flat rock at each site. The surface of 'crafted rock' and general surface of the surrounding area is having same level. It reveals, that the surface of crafted rocks is not only visible today but it would have been visible during the days or period when rock art was made on themby the ancient men. The status of rock surfaces was more or less same during 'art making days' as they are visible today i.e. depth of the soil was same in this landscape as visible today. During observation, it was noticed that the soil depth is thin which is suitable for the development of grassland.

The grasslands of Aravallis are mainly *Dichanthium - Sehima* types i.e. D-S grassland (Dabadghao and Shankarnarayan, 1973; Sharma, 2020). Grasslands of study site are rich in *Dichanthium annulatum, Sehima nervosum, Heteropogon contortus, Eremopogon foveolatus (Dichanthium foveolatum* and *Chrysopogon fulvus. Themeda quadrivalvis, Cymbopogon martini, Eulalia trispicata, Eragrostiella bifaria, Bothriochloa pertusa, Digitaria adscendens, Brachiaria ramosa, Chloris virgata, C. dolichostachya* and *Aristida adscencionis* are other grass species which are seen growing mixed in different composition. The composition indicates that the grassland of Jhalo-Ka-Kalwana is a D-S type grassland.

The 'crafted rocks' are present towards the top or near the top of the piedmonts. Upper area of a piedmont or a hill is more prone to soil erosion than the bottom zone. Therefore, shallow soil exists towards upper reaches and deeper soil layers are seen towards foothill area due to year after year accumulation. Due to less soil depth and more runoff, small height grasses are seen towards the top zone while tall grasses are seen towards the bottom area. It means more visibility remains at top zone in comparison to the bottom area. Rock surface remains exposed towards top zone but same is not found towards the bottom area of a piedmont or a hill. It indicates that crafted surface of all rocks was visible during the period when the art would have been made. Even grasses were of low height during the prehistoric period.

During the early time, three wild animal species namely, tiger (*Panthera tigris*), Indian leopard (*P. pardus*) and sloth bear (*Melursus ursinus*) were common in the area. Last two species are still present in Jarga hills and close to Kumbhalgarh area. Tiger exterminated recently between 1964 – 1970 from this landscape (Singh and Reddy, 2016). Carving of pug marks of sloth bear at location no.1 indicates that prehistoric humans were aware about the threat of wild animals. Elevated sites with grassy vegetation (where visibility was better) were safer than dense forest from the attack of the wild animals. It again indicates that dense forest of low visibility was not present on the piedmonts of Jhalo-Ka-Kalwana but grassy vegetation with good visibility existed during those days.

This interpretation gives a clue that like 'grasslands of Jhalo - Ka - Kalwana' many other grasslands of Gougonda tehsil would have been in 'grassland stage' only during prehistoric period and many of them are not a result of destruction or degradation of the primary forests.

The river Banas is located nearly one kilometer away from the study site. Few years back, this river was perennial in nature. It is still perennial in the foothills of the Jarga hills. Due to presence of three important natural resources namely, perennial source of water, good forest cover and extensive grasslands, this area would have been selected by the ancient men to live and settle down. The prehistoric rock art near Jhalo-Ka-Kalwana is a relic of one of the anthropogenic activities of the ancient men which is indicating their relationship with grasslands.

AGE OF CUP MARKS

Cupules are present at many places in the Aravallis. They are present in the hills of Shilakhadi village of Faridabad district in Haryana. This site is situated in northern Aravallis. Jhalo - Ka - Kalwana (Gogunda tehsil), where cupules are seen, is situated in southern Aravallis. A good knowledge of cupules can be had from Abbas (2014), Bednarik (2001), Pandey et al. (2024) and Shaik (2014 a and b). Exact age of cupules of Jhalo - Ka - Kalwana is not known. It appears that the age of grassland community of Jhalo - Ka - Kalwana is as old as the cup marks of this area are! In India, the earliest manifestation of cupules has been reported from the Auditorium cave of Bhimbetka which is dated back to 29,000 years ago (29,000 BP) (Bednarik, 2001). It is learnt that, the cupules of Jhalo - Ka - Kalwana date back to 10,000 to 20,000 years ago (Late Prof. Lalit Pandey, personal interaction, 2024; Prof. Vinod Agrawal, pers. com. January 5, 2025). Further studies are invited to establish the exact age of the cupules of Jhalo - Ka - Kalwana. Present study indicated that Jhalo - Ka - Kalwana grasslands, present on the piedmonts of the landscape may be formed dated back to 10,000 years or more.

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Ultrasonographic study of gallbladder pathologies in sloth bears: A focus on animal welfare undertaken by Wildlife SOS, Agra, India

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ABSTRACT

The diagnosis of gallbladder pathologies in sloth bears (*Melursus ursinus*) is a critical aspect of veterinary care as they may lead to significant clinical complications. Traditional diagnostic methods often rely on minimally invasive or non-invasive procedures that require chemical immobilization, often stressful for the animals including huge cost involvement of tranquilizing drugs and equipments. This study explores the use of operant conditioning techniques to encourage bears to comply voluntarily with ultrasonography for non-invasive detection of gallbladder pathologies. Ultrasonographic examination of 48 bears was successfully performed by adopting positive reinforcement technique, revealing that 22.9% were diagnosed with cholecystitis, 6.3% with sludge, and 2.1% with a gallbladder polyp. The ultrasonographic findings included hyperechoic non-acoustic shadows indicative of sludge, an irregular and hypoechoic thickened gallbladder wall suggestive of cholecystitis, and an echogenic mass protruding from the inner lining of the gallbladder mucosa, consistent with a polyp. Supportive medications along with nutritional management were adopted to enhance the hepatic function. This study demonstrates the feasibility of using operant conditioning as a part of a co-operative care program for the effective and non-invasive diagnosis of gallbladder pathology through ultrasonography in bears, potentially improving animal welfare and diagnostic accuracy by reducing the need for chemical immobilization.

Key words: Gallbladder pathologies, non-invasive ultrasonography, operant conditioning, sloth bear

INTRODUCTION

Interaction with captive animals promotes physical and mental stimulation, and any carefully tailored behavioral strategy that meets individual or group needs in ex-situ environments contributes to improved animal welfare (Hediger, 1950). Associative learning, including both classical and operant conditioning is fundamental to foster positive human-animal interactions (Rault et al., 2020) our understanding of the underlying processes that govern the positive perception of humans by animals is incomplete. We cover the potential mechanisms involved in the development and maintenance of positive human-animal relationships from the perspective of the animal. This encompasses habituation, associative learning, and possibly attachment or bonding based on communication and social cognition. We review the indicators from the literature to assess a positive human-animal relationship. We operationally define this positive relationship as the animal showing voluntary approach and spatial proximity (seeking, and the application of positive reinforcement in operant conditioning effectively enhances the likelihood of desired behavioural responses (Young and Cipreste, 2004). Positive reinforcement involves rewarding a response or behaviour with something the subject desires (such as foods of preference), thereby increasing the frequency of that behaviour (Jill and MacPhee, 2010; Keller et al., 2020). Shaping is a procedure within operant conditioning and corresponds to a process that can be used to train a certain behavior, through a series of small, selectively reinforced steps (Cipreste, 2014). Wild animals maintained in captivity can be effectively conditioned through structured training techniques that facilitate routine handling and promote voluntary participation in husbandry and veterinary procedures (Skinner, 1951). The implementation of animal training protocols must be systematically planned based on predefined objectives, species-specific behavioral and physiological knowledge, and individual-specific characteristics (Cipreste et al., 2022). This approach facilitates the execution of veterinary procedures in captive animals by promoting their cooperation and reducing stress during handling (Coleman et al., 2005; Mattison, 2012; Ward and Melfi, 2013; Rault et al., 2020; Atchison, 2023). Many facilities are starting to train primates to voluntarily cooperate with veterinary, husbandry, and research procedures, such as remaining still for blood draws or injections. Such training generally reduces the stress associated with these procedures, resulting in calmer animals and, ultimately, better research models. However, such training requires great investments in time, and there can be vast individual differences in training success. Some animals learn tasks quickly, while others make slower progress in training. In this study, we examined whether temperament, as measured by response to a novel food object, correlated with the amount of time it took to train 20 adult female rhesus macaques to perform a simple task. The monkeys were categorized as "exploratory" (i.e., inspected a novel object placed in the home cage within 10 sec. As such, it serves as a viable alternative to traditional chemical (Laule and Desmond, 1998) or physical (Desmond and Laule, 1994) restraint methods, with the potential to minimize trauma associated with these conventional practices (Waiblinger et al., 2006). We briefly explain why an increased understanding of the human–animal relationship (HAR). Ultrasonography has a wide range of utility related to reproduction assessment, assisted reproduction technologies, anatomic, physiologic, and morphological studies (Stefanello et al., 2009). A thorough understanding of the species-specific anatomy is essential before performing ultrasonography, as the absence of such knowledge or prior experience may hinder accurate identification of pathological changes (Hildebrandt and Saragusty, 2015). This study explores the use of operant conditioning within a cooperative care framework to facilitate non-invasive ultrasonographic diagnosis of gallbladder pathology in sloth bears, potentially enhancing diagnostic accuracy and animal welfare.

MATERIALS AND METHODS

Site

The study was conducted on forty-eight (n = 48) sloth bears housed at the Agra Bear Rescue Facility, Agra, Uttar Pradesh, India. The facility is managed by Wildlife SOS, an Indian non-profit conservation organization that has been actively involved in the rescue and long-term rehabilitation of sloth bears formerly exploited in the dancing bear trade. The bears included in this study ranged in age from 5 to 30 years and had an average body weight between 80 and 120 kg.

Exhibit layout

Two enclosures were specifically engineered to facilitate voluntary participation of animals enabling safe and efficient access to the abdominal region. The first structure comprised vertical metal bars with an overall height of 230 cm and width of 103 cm. A horizontal metal bar was positioned at a height of 112 cm from the ground, providing a stable surface for the bear to hook its forepaws and support itself comfortably during the procedure. The exhibit included two strategically placed 15 × 15 cm access ports located at 44 cm intervals from the centreline, with the upper port positioned at 40 cm height and the lower one aligned below, allowing access to different abdominal regions based on bear posture (Fig.1). The second enclosure layout supported abdominal access while the bear was in lateral recumbency, specifically accommodating individuals with musculoskeletal challenges who were unable to maintain a sitting posture for prolonged periods. This structure featured a wider metal-barred front measuring 230 cm in width and height. A single access port (22 × 22 cm) was positioned 10 cm above ground level, allowing unobstructed access to the lateral abdominal surface (Fig. 2).

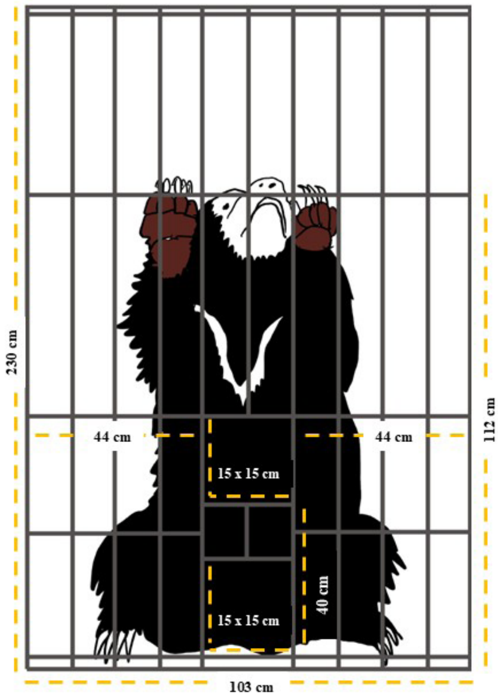

Fig. 1. Enclosure modification to facilitate abdominal ultrasonography in a seated (vertical stationing) posture

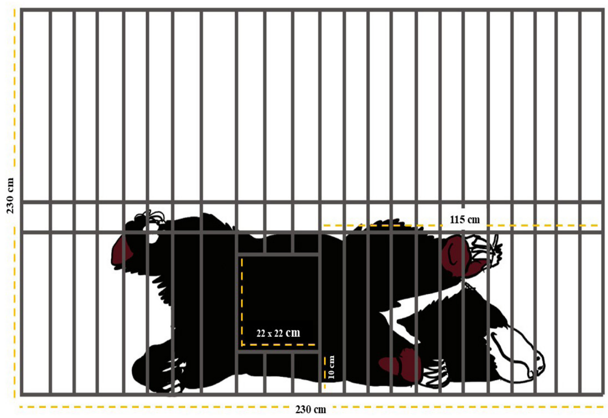

Fig. 2. Modified enclosure design facilitating abdominal ultrasonography in lateral recumbency

Behavioural training

A structured operant conditioning approach was employed using positive reinforcement techniques. A target stick was utilized to guide individuals to a designated location (stationing). Each subject underwent daily training sessions, with trials conducted twice, depending on the complexity of the behavior being taught. Each session was subdivided into three parts, lasting between 3 to 6 minutes, interspersed with 1 minute break. A single trial continued until the subject successfully performed the target behavior three times consecutively. A clicker served as the conditioned reinforcer; the click sound was delivered immediately following the desired behavior to signal the impending delivery of a primary reinforcer. Food rewards, used as positive reinforcers, were administered promptly following the appropriate behavioral response. A behavior was considered to be learned when the subject could demonstrate the target behavior reliably and confidently, completing three successful repetitions. Details of specific behaviors targeted and the reinforcement criteria are outlined below (Table 1).

Table 1. Criteria for reinforcement during operant conditioning of sloth bears

Behaviour	Criteria for reinforcement
Target	Bear touches target stick with nose
Sit	Bear has back (hind paws) end on ground front end (fore paws) held up by hooked into bar that divides mesh sections
Lay down	Bear turns head, shoulder, and hips in and lays on side (laterally)

Desensitization

The desensitization process was incorporated through step-wise exposure to ultrasonography-related stimuli depending on each individual's comfort and response. Initially, bears were acclimated to gentle abdominal touch by hand with calm behaviour positively reinforced. Once basic tactile contact was tolerated, light pressure using anon-functional PVC pipe was introduced to stimulate ultrasound probe contact. Subsequently, the bears were gradually exposed to presence and sound of a trimmer and the ultrasound unit (visual and auditory stimuli) followed by the application of ultrasound gel using gloved hands. This was followed by brief and progressively longer sessions with the actual probe and machine in operation. The procedure was considered successful when the bear remained relaxed and cooperative during full simulated scanning without signs of stress or avoidance.

Hepatobiliary ultrasonography

Due to the dense fur covering of sloth bears, abdominal fur was clipped to ensure optimal acoustic coupling during transcutaneous ultrasonographic examination. Abdominal ultrasound was performed (Fig. 3 and 4) on 48 bears using the LOGIQ e (GE Medical Systems, China) equipped with a 4C convex probe (1-8 MHz). Gallbladder wall thickness was measured, with values exceeding 3 mm considered indicative of increased wall thickness. Moreover, the gallbladder was assessed for wall echogenicity, presence of wall edema, and intraluminal contents (i.e., sediment, sludge, and gallstones). In addition, the liver was evaluated for echogenicity and overall morphological appearance.

RESULTS AND DISCUSSION

Gallbladder ultrasonography was successfully performed in 48 sloth bears. Out of these, 33 individuals (68.75%) showed no abnormality detected (NAD). Gallbladder lesions were detected in 15 bears (31.25%). The most common finding was cholecystitis, observed in 11 bears (22.91%), characterized by increased gallbladder wall thickness (>3 mm), hyperechoic wall margins, and occasionally pericholecystic fluid. Sludge was detected in 3 bears (6.25%), visualized as echogenic material without acoustic shadowing. A single case (2.08%) of a gallbladder polyp was identified as a well-defined echogenic intraluminal mass (Fig. 5). Representative ultrasonographic images of gallbladder abnormalities observed in the study are presented in Fig. 6-11.

Fig. 3. Operant conditioning-assisted ultrasonographic examination of the gallbladder in a seated sloth bear

Fig. 4. Abdominal ultrasonographic examination conducted under lateral recumbency.

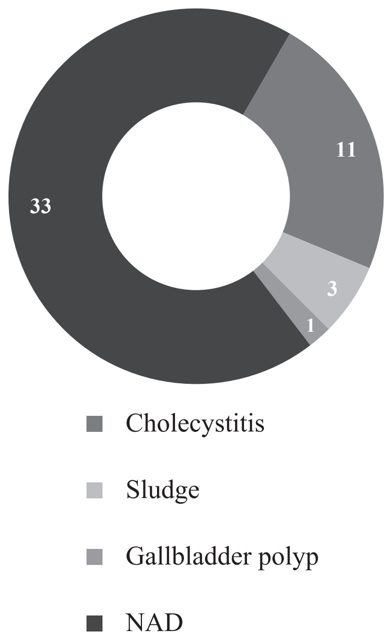

Fig. 5. Donut chart representing the distribution of gallbladder pathologies

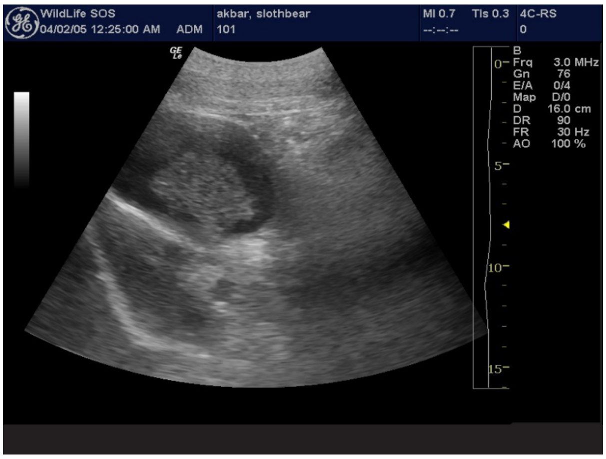

Fig. 6. USG showing presence of sludge in gallbladder

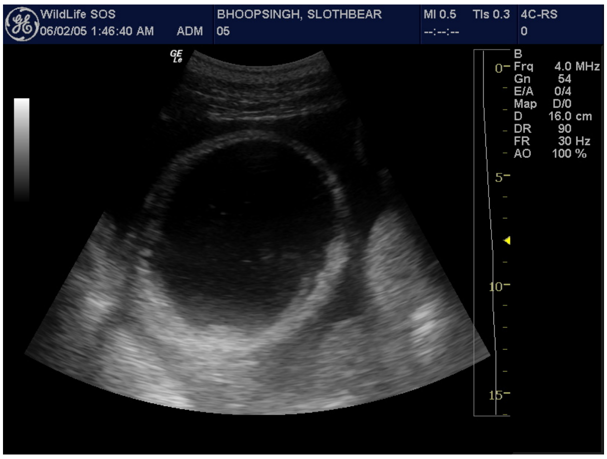

Fig. 7. Thickened gallbladder wall with abnormal bile consistency

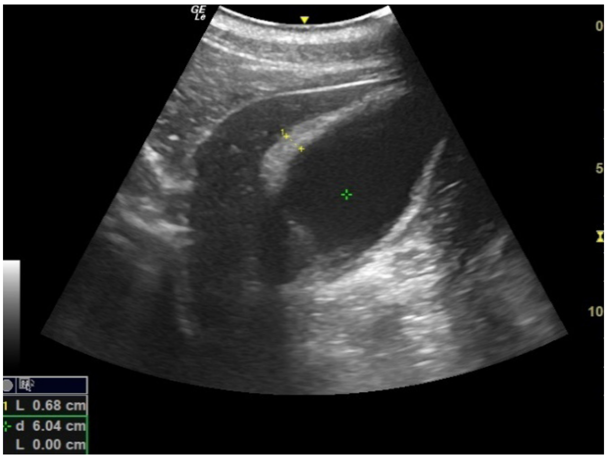

Fig. 8. Thickened gallbladder wall, suspected for cholecystitis

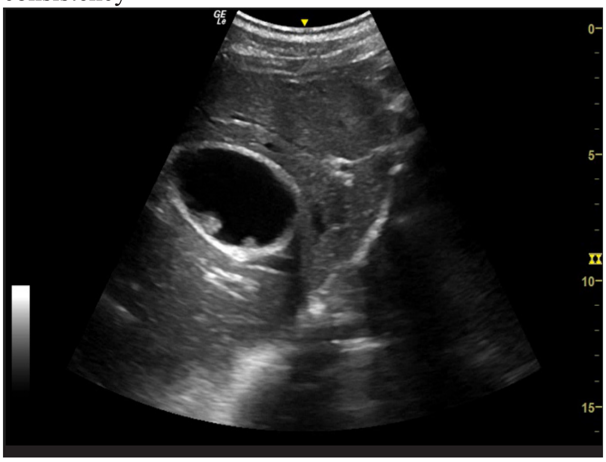

Fig. 9. Ball on the wall sign; gallbladder polyp

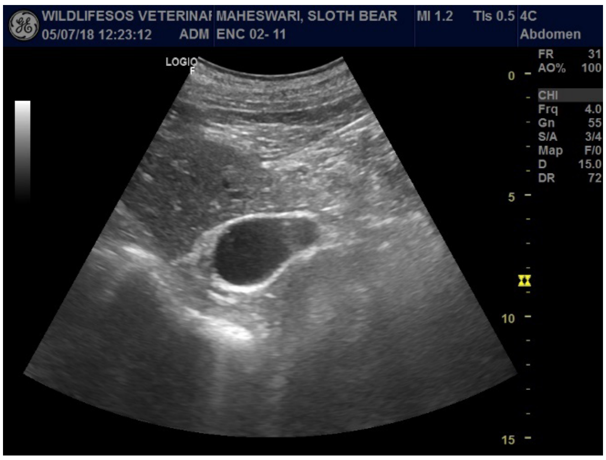

Fig. 10. Pericholecystic fluid with hyperechoic gallbladder wall

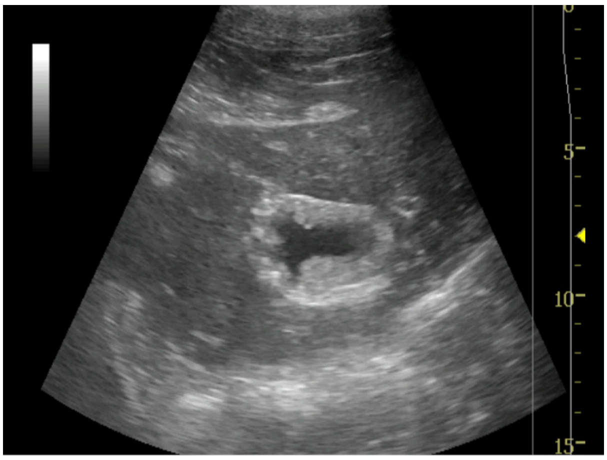

Fig. 11. USG showing hypertrophy of gallbladder wall

The predominance of cholecystitis (22.91%) is of clinical significance, possibly indicating subclinical inflammation or early biliary disease in a population previously subjected to compromised health. Detection of biliary sludge (6.25%) may suggest bile stasis or increased bile concentration. The single gallbladder polyp observed warrants continued surveillance for potential neoplastic transformation, although such findings are infrequently reported. However, the prevalence of subtle hepatobiliary alterations underscores the utility of routine ultrasonographic monitoring as a non-invasive diagnostic tool to inform preventive veterinary care in long-term captive populations.

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Mammals of Khalasuni Wildlife Sanctuary, Western Odisha, India: An overview

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ABSTRACT

Camera traps were deployed at 180 stations in Khalasuni Wildlife Sanctuary between 14th November 2021 and 28th April 2022 that provided the effort of 4500 trap-nights. Out of the total photos captured, 24 large and medium-sized mammals belonging to 14 families were recorded in the study area. Photos of six threatened species categorised under the IUCN Red List were captured, namely leopard (*Panthera pardus)*, sloth bear *(Melursus ursinus)*, Asian elephant *(Elephas maximus)*, gaur (*Bos gaurus)*, sambar *(Rusa unicolor)*, and four-horned antelope *(Tetracerus quadricornis).* Sambar *(Rusa unicolor)* was found to be the most frequently photographed and four-horned antelope was the most widespread species of the sanctuary. Photographic evidence of mammalian species were documented and the importance of conservation of threatened and vulnerable species in the study area were analysed.The current camera trap survey is expected to help in formulating management strategies for long-term conservation of mammalian species in Khalasuni Wildlife Sanctuary.

Key words: Camera trapping, mammalian diversity, Odisha, relative abundance index

INTRODUCTION

Camera trapping has been proven to be an effective method in monitoring elusive and nocturnal species along with population estimation of naturally marked individuals using spatially explicit capture-recapture models (Karanth and Nichols 1998; Harihar et al. 2014). Camera traps have become an important tool for inventorying and estimating species diversity at a site (Cutler and Swann, 1999; O'Connell, et al., 2011). Mammals can also act as apex predators, regulating the populations and behavior of their prey, which can impact the structure and composition of the forest community. Despite their vital role in forest ecosystems, they face a multitude of threats that can significantly impact their populations. Habitat destruction and fragmentation due to human activities such as deforestation, mining, and urbanization are some of the most significant threats to mammal communities in the world. Camera trapping is an increasingly popular method to study wildlife. While there are several types of camera traps, all models have the same basic principle: a photo (and / or video) camera protected by some sort of weather-proof housing, coupled to a mechanism that allows the camera to be triggered automatically when an animal moves in front of it. The camera traps were first used to estimate the density of tiger *(Panthera tigris)* populations in India (Karanth, 1995). Later this methodology has been widely used to study the density of leopards (*Panthera pardus)* (Henschel and Ray, 2003; Kostyria et al., 2003). Due to increasing anthropogenic pressure, half the world's 5491 known mammalian species are declining and a fifth are clearly on the verge of extinction (Anon. 2016). Although the use of relative abundance index (RAI) generated from camera trap encounter rates is controversial as it gets biased with animal body mass and study design (Sollmann et al., 2013), there are examples of a linear relationship between RAI and abundance, estimation, especially of cryptic species (Gonthier et al., 2013; Karantha et al., 1998; Datta et al., 2008; Jenks et al., 2011 and Lahker et al., 2018).

In Odisha several mammalian studies have been reported; (Tiwari et al., 2002) first compiled 37 species of mammals from Chandaka-Dampara Wildlife Sanctuary. In Similipal Biosphere Reserve 55 species , Kotagarh Wildlife Sanctuary 43 species, Kuldiha Wildlife Sanctuary 20 species, Sunabeda Wildlife Sanctuary 22 species, Hadgarh Wildlife Sanctuary 19 species Debrigarh Wildlife Sanctuary 27 species, Sundargarh Forest division 27 species, Nayagarh District 29 species, Keonjhar Forest Division 25 species and Bonai Forest Division 28 species recorded (Debata and Swain, 2020; Debata et al., 2018; Palei et al., 2020; Palei et al., 2021; Palei et al., 2023a; Palei et al., 2023b; Sarangi et al., 2024; Dhanraj et al., 2025 and Patra et al., 2025). In this study, we used camera-trap surveys to study the presence of largeand medium-sized mammals in the Khalasuni Wildlife Sanctuary, Northwestern periphery of Odisha State.

MATERIALS AND METHODS

Study area

The Khalasuni Wildlife Sanctuary is located between latitude of 21^0-15' to 21^0-25' N and longitude of $84^0$15' to $84^0$35' E (Fig. 1). The sanctuary covers 116 sq km and it is dominated by moist peninsular low-level Sal Forest, Northern moist mixed deciduous forest, moist peninsular valley sal forest, dry peninsular sal forest, northern dry mixed deciduous and dry bamboo breaks (Champion and Seth, 1968). Due to good rainfall in the sanctuary area, moist peninsular high-level sal and moist mixed deciduous forests are noticed, along with extensive bamboo forests. The sanctuary shares its boundaries with which covers forest areas of Deogarh Forest Division, Rairakhol, Sambalpur South Forest Division and Bamra Wildlife Division. The mean daily temperatures in winter range from 5˚C to 20˚C and that of summer range from 30˚C to 49.5˚C. There are three distinct seasons namely summer (March to June), monsoon (July to October) and winter (November to February). The rainfall of the Sanctuary and the nearby areas varies from 698 mm to 1962 mm.

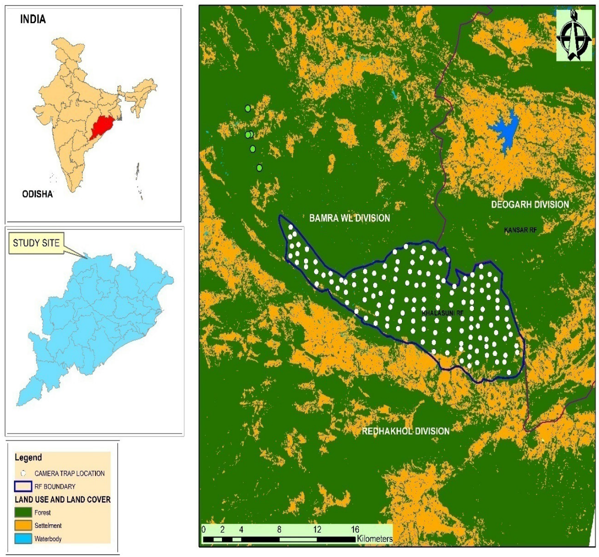

Fig. 1. Location map with camera trap installation in Khalasuni Wildlife Sanctuary, Sambalpur, Odisha

Methodology

Camera trap surveys were conducted in the sanctuary in four phases from 14^{th} November to 21^{st} December 2021: first phase with 45 camera trap stations, 26^{th} December 2021 to 25^{th} January 2022 second phase with 45 camera trap stations and 29^{th} January to 13^{th} March 2022 third phase with 45 camera trap stations and fourth phase 15^{th} March to 28^{th} April 2022 with 45 camera trap stations

(Table 1). Finally, 180 motion sensor camera traps (Cuddeback Model C1) grid wise were set up in the sanctuary. Authors used 2×2 km^2 grids to guide camera placement hole ranges. Camera traps were predominantly set along forest roads, game trails and footpaths. All camera traps were strapped to trees approximately 45 cm above ground. At each location, a pair of traps on either side of the path facing each other was set up to photograph simultaneously both flanks of the animal passing between the cameras. Each location consisted of one pair of camera trap and was set to operate 24 hour and programmed to delay sequential photographs by 30 second delay time for capturing 25 days, yielding a total of 4500 trap nights. Each camera traps was checked at least once a week for battery level, positioning and to replace memory (SD) cards. Each photograph was manually checked to identify the species. Total sampling effort was calculated as the sum of the effective days across all stations that each camera was functioning (Boitani and Powell, 2012). The photos were separated by at least 30 minutes as independent events (Ohashi et al., 2013; Guo et al., 2017). Data on large and medium sized mammals, birds, reptiles, human traffic and livestock including date time, year and behaviour were collated from camera trap photographs. Data on large and medium sized mammals, human traffic and livestock including date time, year and behaviour were collected from camera trap photographs. Relative abundance index (RAI) was calculated as:

$$RAI = (A/N) \times 100$$

Where A is the total number of independent detections of a species by all cameras and N is the total number of camera trap days by all the cameras throughout the study area following Jenks et al., 2011.

Table 1. Summary of camera trap sampling in Khalasuni Wildlife Sanctuary from November 2021 to May 2022

Sampling Period	Sampling days	No. of camera stations	Trap nights (effort)	Total photo captured (Clear, hazy and blurry mixed together)
14th Nov 21 to 21st Dec 2021	25	45	1125	5476
26th Dec 21 to 25th Jan 2022	25	45	1125	4426
29th Jan 22 to 13th Mar 2022	25	45	1125	2569
15th Mar 22 to 28thApr 2022	25	45	1125	5169
Total		180	4500	17640

RESULTS AND DISCUSSION

During a sampling period of 4500 trap-nights using 180 camera traps, a total of 24 species of wild mammals, belonging to 14 families in 6 orders, were recorded in the study area (Table 2). Carnivora was the most diverse order with 13 species, followed by Artiodactyla with 6 species, primates with two, and all other orders with a single species each (Table 2; Fig. 2). Of the 24 species recorded, 6 were Threatened (two 'Endangered', four 'Vulnerable'), 2 'Near Threatened' and 16 'Least Concern' on the IUCN Red List as reflected in Table 2. According to the Indian Wildlife Protection Amendment Act (2022), 19 species were listed in Schedule I, 2 species in Schedule II and 3 species schedule III category (Table 2). According to RAI, the most abundant mammal in the study area was sambar (RAI=2.33), followed by wild boar (1.00), Indian gaur (RAI=1.07), Asian elephant (RAI=1.64), hanuman langur (*Semnopithecus entellus*) [RAI=1.20] and sloth bear; *(*RAI=1.02*)*.

Fig. 2. Camera trap images of threatened mammals recorded in the study area of Khalasuni Wildlife Sanctuary, Odisha: a- Leopard (*Panthera pardus);* b- Rusty spotted cat *(Prionailurus rubiginosus;* c- Indian grey wolf *(Canis lupus);* d- Sloth bear (*Melursus ursinus);* e- Asian elephant (*Elephas maximus);* f- Gaur (*Bos gaurus);* g- Sambar (*Rusa unicolor*); h- Four-horned antelope (*Tetracerus quadricornis)*

Table 2. Comparative Relative Abundance Index (RAI) of different wildlife species and others based on camera trap photographs in Khalasuni Wildlife Sanctuary during the field-work with their current IUCN status

Sl. No	Common name	Order	Family	Scientific names	WPA status	IUCN status	Total photo captured	RAI
1	Leopard	Carnivora	Felidae	*Panthera pardus*	I	VU	64	1.42
2	Jungle cat	Carnivora	Felidae	*Felis chaus*	I	LC	32	0.71
3	Rusty spotted cat	Carnivora	Felidae	*Prionailurus rubiginosus*	I	NT	8	0.18
4	Indian grey wolf	Carnivora	Canidae	*Canis lupus*	I	LC	12	0.27
5	Golden jackal	Carnivora	Canidae	*Canis aureus*	I	LC	32	0.71
6	Striped hyeana	Carnivora	Canidae	*Hyaena hyaena*	I	NT	8	0.18
7	Indian fox	Carnivora	Canidae	*Vulpes bengalensis*	I	LC	9	0.20
8	Sloth bear	Carnivora	Ursidae	*Melursus ursinus*	I	VU	46	1.02
9	Ratel	Carnivora	Mustelidae	*Mellivora capensis*	I	LC	26	0.58
10	Small Indian civet	Carnivora	Viverridae	*Viverricula indica*	I	LC	10	0.22
11	Common palm civet	Carnivora	Viverridae	*Paradoxurus hemaphroditus*	I	LC	15	0.33
12	Grey mongoose	Carnivora	Herpestidae	*Herpestes edwardsii*	I	LC	13	0.29
13	Ruddy mongoose	Carnivora	Herpestidae	*Herpestes smithii*	I	LC	6	0.13
14	Asian elephant	Proboscidae	Elephantidae	*Elephas maximus*	I	EN	74	1.64
15	Indian gaur	Artiodactyla	Bovidae	*Bos gaurus*	I	VU	48	1.07
16	Sambar	Artiodactyla	Cervidae	*Rusa unicolor*	I	VU	105	2.33
17	Four-horned antelope	Artiodactyla	Bovidae	*Tetracerous quadricornis*	I	EN	40	0.89
18	Barking deer	Artiodactyla	Cervidae	*Muntiacus muntjak*	I	LC	28	0.62
19	Mouse deer	Artiodactyla	Tragulina	*Moschiola Indica*	I	LC	12	0.27
20	Wild boar	Artiodactyla	Suidae	*Sus scrofa*	III	LC	45	1.00
21	Indian crested porcupine	Rodentia	Hystricidae	*Hystrix indica*	I	LC	26	0.58
22	Rhesus macaque	Primates	Cercopithecidae	*Macaca mulatta*	II	LC	47	1.04
23	Hanuman langur	Primates	Cercopithecidae	*Semnopithecus entellus*	II	LC	54	1.20
24	Indian hare	Lagomorpha	Leporidae	*Lepus nigricollis*	III	LC	28	0.62

RAI- Relative Abundance Index, IUCN- International Union for Conservation of Nature, EN- Endangered, VU- Vulnerable, NT- Near threatened, LC- Least concern, IWPA- Indian Wildlife Protection Act (2022).

The camera trapping study revealed the presence of high diversity of terrestrial mammals, as evident from a comparison with camera trap studies in other nearby forest landscapes, e.g. 24 mammals over 6413 trap nights in 187 camera trap stations in Similipal Tiger Reserve (Palei et al. 2016), 20 mammals over 916 trap-nights in 65 camera trap stations in Kuldiha wildlife sanctuary (Debata and Swain 2018), and 19 mammals over 2049 trap-nights in 60 camera trap stations in Hadgarh wildlife sanctuary, Odisha, India (Palei et al. 2022). 18 mammals over 750 trap night; in 25 camera trap stations in Northern Reserve Forest, Athmallik Forest Division (Palei et al. 2024); 25 mammals over 6329 trap night in 165 camera trap station in Badrama Wildlife Sanctuary (Palei et al., 2022); 27 mammals over 3150 trap night in 123 camera trap station in Debrigarh wildlife sanctuary (Palei et al., 2023); 27 mammals over 3134 trap night in 81 camera trap station in Sundargarh Forest Division (Palei et al., 2023); 29 mammals over 2850 trap night in 122 camera trap station in Nayagarh Forest Division (Sarangi et al., 2024); 25 mammals over 3214 trap night in 53 camera trap station in Keonjhar Forest Division (Dhanraj et al., 2025). Here 24 mammals over 4500 trap nights in 180 camera trap stations in Khalasuni wildlife sanctuary were reported.

The study confirmed that among the 24 mammalian species recorded during the camera trap survey, carnivore species were the most common at each study site followed by herbivores. Sambar was the most frequently detected species. The species is considered common in India because of its adaptabe nature (Menon, 2014). The elephant is a large-bodied herbivore that occurs throughout the sanctuary. Other species like gaurs, sambars, mouse deer, northern muntjaks and wild boars are widely distributed in the entire Khalasuni Wildlife sanctuary. The Indian grey wolf is confined to the sanctuary and photo captured in one location whereas the golden jackal shows patchy distribution, and is not recorded in the southern part of the sanctuary, though it is occasionally seen in the central and the northern part of the sanctuary. As per camera trap records there is no photo capture of chitals *(Axis axis)*, in the sanctuary. The common palm civet *(Paradoxurus hermaphroditus)*, the small Indian civet (*Viverricula indica),* the grey mongoose *(Herpestes edwardsii)* are widely distributed in the sanctuary, while the ruddy mongoose *(Herpestes smithii)* is confined to a limited area of the sanctuary. The sight records of jungle cats (*Felis chaus)*, and rusty spotted cats *(Prionailurus rubiginosus)* are available from limited area of the sanctuary. The honey badger *(Mellivora capensis)* is known only from a few locations of the sanctuary. Sloth bear was the second most detected species may be due to their high population size contrary to other studies (Palei et al. 2016; Debata and Swain 2018; Palei et al. 2022). Indian gaur is common in thestudy area and has the high detection rate, contrary to other studies conducted in nearby localities (Palei et al., 2016; Debata and Swain 2018; Palei et al., 2018, 2023; Palei et al., 2019) Odisha, India. Two individuals of Indian grey wolf were recorded during the survey offering the first photographic evidence of the Indian grey wolf outside protected areas of Odisha. This record increases knowledge on the distribution of the species. More extensive surveys are needed to understand the distribution and population dynamics of Indian grey wolf in the area. We provide photographic evidence of Indian grey wolves and highlight the importance of Odisha forest for species conservation. This survey provides crucial evidence to inform and support conservation efforts within the Khalasuni wildlife sanctuary and neighbouring regions. To improve species detection, we recommend that future camera trapping campaigns cover a broader elevational range and a wider variety of microhabitats. In addition, evaluating livestock depredation by leopards and developing compensation strategies for herders are essential steps towards the long-term conservation of this species. Finally, we urge that the area's protection status be upgraded.

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Activity time budget of Asian elephants in Northwest India: A case study from Rajaji National Park, India

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ABSTRACT

The study was undertaken to understand the activity time budget of Asian elephants in Rajaji National Park, Northwest India. A total of three elephants were selected from an identified group (one adult female, one subadult female and one juvenile). Besides, a solitary adult male elephant was also identified separately for observing the activities. Activities were classified into three broader heads i.e. feeding, movement and associated other behavioural activities. Literature reveals that the budgeting of different activities within a specified period of time provides an opportunity to analyse their strategies of behavioural patterns which can also help in the management of the species. This type of field study is of paramount importance and it's outcomes being significant can be incorporated into management plans.

Key words: Activity time budget, Asian elephants, behavior, Rajaji National Park

INTRODUCTION

Large-range movements in wild animals help them adjust to immediate changes in the environments and develop the ability to maintain population continuity for gene flow. It also influences plant community dynamics through seed dispersal and thus shape the biodiversity. Animal movement is a core component of an ecosystem and maintaining movement patterns may be vital for sustaining ecosystem processes like trophic and species interactions (Lundberg and Moberg, 2003; Massol et al., 2011). The Asian elephants (*Elephas maximus*) in India were once known to migrate from the river Yamuna (in the north) to the Brahmaputra (in the east), travelling a distance of approximately 1,300 kilometers across the foothills of the Himalayas (Singh and Sharma, 2001). Though, movement of species across new grounds results in competition for space and resources and sometimes human-animal conflict also, it provides scope of addressing the edge effects and habitat fragmentation. The field of movement ecology has grown rapidly in the last decade and is now providing the knowledge needed to incorporate movements of species into management planning (Allen and Singh, 2016).

Information on activity time budget of animals helps in the analysis of their foraging and survival strategies, which vary according to the habitat, temperature and rainfall (Vinod and Cheeran, 1997). Elephant activity budget can be defined as "different activities an elephant is involved in or exposed to in a given unit of time" (McKay, 1973; Ahamed, 2015; Booth and Doble, 2022). Rees (2009) reported that activity budgets in eight Asian elephants exhibited variation in activity depending on their age, sex, the time of day and the time of year. This study was done to understand the activity time budget of Asian elephants in Rajaji National Park, Northwest India. The Rajaji National Park is located in Northwest India at 29°51'-30°15'N, 77°52'-78°22' E (elevation 302-1000 m). It falls within the Gangetic plains biogeographic zone (Rodgers et al., 2002) and is dominated by northern tropical moist and drydeciduous forest. Although sal forest occupies a major portion of the park, northern tropical moist deciduous forest, sub-tropical pine forest, tropical dry-deciduous forest, riverine forest and low alluvial Savannah woodland also enrich park's floral diversity.

The dominant vegetation of the study area consists of *Shorea robusta* Gaertner f. (Sal), *Mallotus philippensis* (Lam.) Mull. Arg. (Kamala), *Acacia catechu* (L.f.) Willd. (Cutch), *Haldina cordifolia* (Roxb.) Ridsdale (Kadam), *Terminalia bellirica* (Gaertn.) Roxb. (Bahera), *Ficus benghalensis* L. (Indian Banyan) and *Dalbergia sissoo* Roxb. ex DC (Indian Rosewood). Besides, the elephant as the flagship species, the dominant mammalian fauna of the park consists of *P. tigris* (tiger), *P. pardus* (leopard), *Ursus thibetanus* (Himalayan black bear), *Melursus ursinus* (sloth bear), *Hyaena hyaena* (hyaena), *Muntiacus muntjak* (barking deer), *Naemorhedus goral* (goral), *Axis axis* (spotted deer), *Rusa unicolor* (sambar) and *Sus scrofa* (wild boar).

MATERIALS AND METHODS

Different activities of the elephants were observed over a period of one year, considering nine hours of the day (between 06.00 hr and 18.00 hr) in three seasons, summer (March to June), monsoon (July to September) and winter (October to February). Activities were classified into three broader heads i.e. feeding, movement and associated other behavioural activities (Fig. 1-6). Each day was divided into four time blocks: early morning (06.00-09.00 hrs), midday/afternoon (12.00-15.00 hrs) and evening (15.00-18.00 hrs).

A total of three elephants were selected from an identified group (one adult female, one subadult female and one juvenile). Besides, a solitary adult male elephant was also identified separately for observing the activities. A total of 2,160 hours (12×15 days/month × 12) were spent in observing the animal and analyzing the activity budget (with 7200 scan samples; 40 per day). An ethogram was developed identifying different behaviours (Whilde and Marples, 2011; Ahamed, 2015; Booth and Doble, 2022) based on the study (Table 1).

Table 1. Ethogram of Asian elephant under the study

Sl.No.	Behaviour	Definition
1	Walking	Movement from one area to another
2	Resting	Animal is stationary, not performing any other behaviour
3	Drinking	Elephant takes water through trunk, passes water into its mouth
4	Bathing	Immersed in water
5	Feeding	Elephant uses trunk to pick up food, puts food in mouth
6	Playing	trunk wrestling, head-to-head sparring, mounting and rolling on one another
7	Excretion	Urination or defecation
8	Dusting	Elephant takes mud/ loose earth in its trunk, sprays it on its body
9	Standing	Elephant standing on its feet, not moving
10	Flapping the ears	To and fro movement of ears
11	Exploring	Elephant investigates any objects using its trunk in its environment
12	Tail swiveling	The tail goes stiff and normally held out to one side

Fig. 1. A tusker bathing at a waterhole at Chillawali forest

Fig. 2. A male elephant spraying mud over its body

Fig. 3. A female elephant breaking a twig of a juvenile tree with its forefoot to feed

Fig. 4. Two female elephants trying to climb up a high hillock, keeping the baby in the middle

Fig. 5. Tactile communication: Two female elephants while communicating with each other

Fig. 6. A bull elephant during charge

RESULTS AND DISCUSSION

For matriarchal group of elephants, feeding activity during the winter accounted highest (7.40 hours), followed by the monsoon (6.45 hours) and summer (6.15 hours). In contrast, movement activity accounted maximum during the summer (1.25 hours), followed by the monsoon (0.50 hours) and winter (0.35 hours). Associated other behavioural activities, which include resting, drinking, bathing, interacting with each other, nursing calves and play, defecation, dusting, standing and flapping the ears, exploring, tail swiveling and greetings accounted highest during monsoon (1.25 hours), followed by summer (1.20 hours) and winter (0.45 hours). It is worth mention that the movement activity depends on the availability of resources in the given area. For adult male elephant, feeding activity accounted highest for winter (6.45 hours), followed by monsoon (6.10 hours) and summer (5.15 hours). Similarly, movement activity with respect to male elephant was recorded highest during summer (1.25 hours), followed by monsoon and winter, respectively (1.15 hours). Associated other behavioural activities were recorded highest during summer (2.20 hours), followed by monsoon (1.35 hours) and winter (1.0 hours), respectively. Activities of matriarchal group of elephants and solitary adult male elephant in different seasons along with duration of activity are depicted in Table 2 and Fig. 7.

Table 2. Activities of matriarchal group of elephants and solitary adult male elephant in different seasons along with duration of activity

Season	Activities					
	Feeding		Movement		Associated behavioural activities	
	Matriarchal group	Male elephant	Matriarchal group	Male elephant	Matriarchal group	Male elephant
Summer	06:15	05:15	01:25	01:25	01:20	02:20
Monsoon	06:45	06:10	00:50	01:15	01:25	01:35
Winter	07:40	06:45	00:35	01:15	00:45	01:00
Total	20:00	18:10	02:50	03:55	03:30	04:55

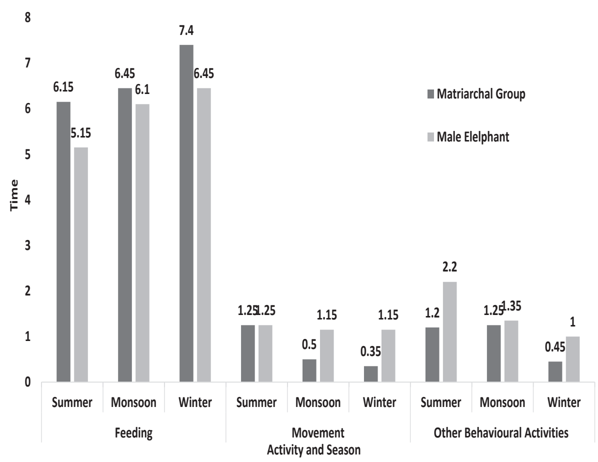

Fig. 7. Duration of the activities in different seasons as observed in the identified individuals of matriarchal group and solitary adult male elephant

Vinod and Cheeran (1997) found that Asian elephants in Idukki WLS spent 65% of their time feeding in dry season, while it accounted for 80% in wet season. The study revealed that elephants spent more time on feeding during wet season. However, grazing was found to be predominant in both dry season 63% and in wet season 71%. The amount of time that an animal or group of animals spends in any particular activity indicates a trend of the time budget, which varies from day to day. Generally, elephants became more active before dawn and start their morning activities in the vicinity of the area where they spent night. During the summer, feeding activity was observed maximum during the morning and evening hours, however, during the mid-day, members of the group and bull elephants prefer to take rest in available cooler areas under the large trees and begin their activities in the evening, which were quite similar to the morning activities. However, in winter, feeding activity is almost constant throughout the day and elephants consume less time in resting activities. In summer, movement activity was recorded maximum as natural water sources dry during the period and elephants also move along the riparian corridor to feed on succulent forage like bark of teak wood, kut-sagaun and Indian rosewood. During the monsoon, the movement and feeding activities slightly fluctuates, especially among the groups because of availability of rainwater reservoirs in shorter distances. Similarly, as there is less requirement of water during winter,movement activity was observed less. Resting follows the standing of elephants in any cool shaded areas under trees like *Ficus bengalensis, Adina cordifolia and Butea monosperma*. However, during the winter, elephants prefer to stand and feed in open areas. Early morning and evening hours were the times to drink and bathe especially during summer.

Conflict between humans and elephants most often arises in areas adjacent to elephant habitats, particularly where people cultivate crops. Apart from fragmentation, sometimes the lack of water or food inside the forests also forces the elephants to move to the outskirts of the forest. Literature reveals that the budgeting of different activities within a specified period of time provides an opportunity to analyse their strategies of behavioural patterns which can also help in the management of the species. It is imperative that field studies are conducted extensively so that the outcomes are incorporated into the management plans.

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Assessment of community led conservation efforts and butterfly diversity in the periphery of Satkosia Tiger Reserve, Angul, Odisha, India

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ABSTRACT

In total, 93 species were documented across 21 unique transects in community restored area highlighting the comprehensive nature of the survey and its potential to contribute to our understanding of butterfly ecology in the periphery of Satkosia Tiger Reserve. The Shannon diversity index, a measure of species diversity that considers both abundance and evenness, ranges from 2.3 to 3.5 across the surveyed sites. The abundance of butterfly species was almost same across all types of habitat. The mean Shannon Diversity Index for the entire study area was calculated to be 3.05, reflecting the richness and variety of butterfly species observed during the survey. The surveyed sites include areas such as forests, fallow lands, and agricultural land, representing diverse ecological habitats. Among all the land uses, maximum butterfly richness and abundance were recorded in forests followed by agricultural and fallow lands.

Key words: Angul, butterflies, community restoration, ecology, habitat, land-use

INTRODUCTION

Restoration, not only provides livelihood sbut also support diversity, and ecological services which are required for the smooth functioning of ecosystem (Hobbs and Harris, 2001; Benayas et al., 2009). To measure the ecosystem, health and community efforts to restore the common butterflies is one of the major indicators for assessment and understanding the change in habitat quality of the landscape (Bonebrake et al., 2010; Kremen, 1992).

The butterflies play a vital role in different ecosystems and are important indicators of healthy environment and ecosystems (Ghazanfar et al., 2016). There is a co-evolutionary relationship between butterflies and plants, indicating that their lives have close ecological inter-linkages (Paul et al.,1964). Butterflies are an important components of food chain as they act as prey for small mammals, reptiles, amphibians, birds, and other insects. Additionally, butterflies play a crucial role in pollination for wild plants and agricultural crops by carrying pollen from one plant to another plant far apart and induce genetic variation in the plant species (Kumar et al., 2021). Ecologists also use butterflies as model organisms to study the impact of climate change and habitat loss, since they are pollination sensitive and cannot survive under unfavorable environmental conditions (Hill et al., 2021).

MATERIALS AND METHODS

The present study has been conducted in the periphery of Satkosia Tiger Reserve covering 7200 hectare area in Angul district, located in central Odisha during September to October, 2023 (Fig. 1). This area is characterized by undulating topography, interspersed by streams and rivulets flowing into the two major river systems- Brahmani and Mahanadi. It has a rich forest with an elevation ranging between 152-823 meters. The Satkosia Gorge Wildlife Sanctuary is a characteristic feature of the area.

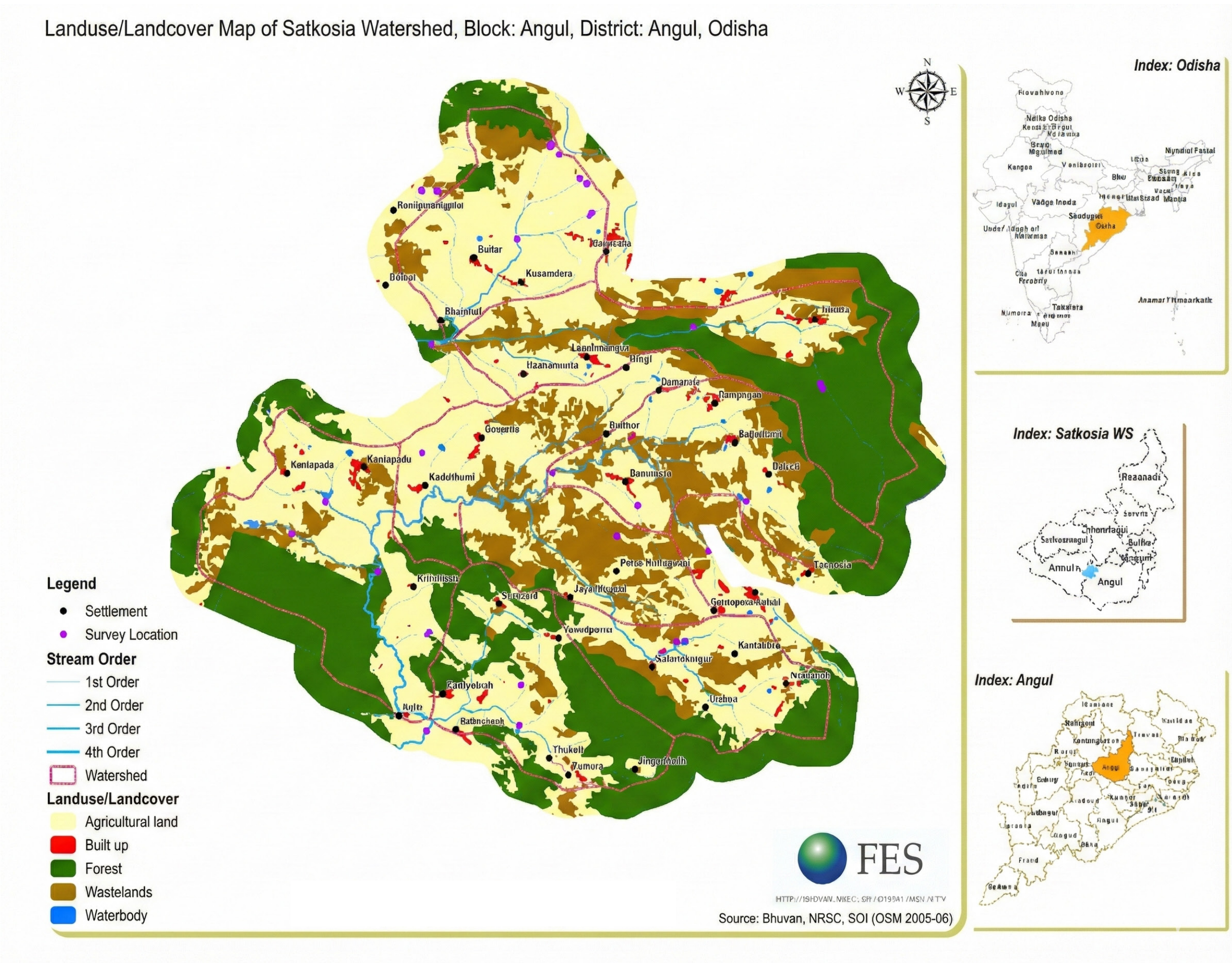

Fig. 1. Map of study area (not in scale)

The monitoring protocol was based on modified Pollard walks (Koh and Sodhi, 2004; Pollard and Yates, 1993). Transects were visited between 10:00 and 16:00 hours. Transects (approximately 500m length and 20m breadth) were walked in one direction at a slow and even pace (~1-2 km/h) for a duration of 25-30 minutes on clear days. Quantitative sampling was done systematically across 18 locations covering five different habitats, namely, agricultural land, agricultural fallow land, fallow land, forest and grassland. Species level identification was done using keys (Kehimkar, 2008; Kunte, 2000 and Mohapatra et al., 2012) and mostly photographic documentation was carried out. The analysis of the species observed was done with the help of Shannon-Wiener Index (H), Evenness (J), Simpson's Index/Dominance, Simpson's Index of diversity (1-D) were Simpson's Reciprocal Index (1/D) (Magurran, 1988; Pielou, 1969).

RESULTS AND DISCUSSION

A total of 1674 butterflies representing 93 species belonging to 6 families were recorded (Table 2) during the study period. The highest representation was from Nymphalidae (33 species), followed by Lycaenidae (20 species), Hesperiidae (21 species), Pieridae (11 species), Papilionidae (7 species) and Riodinidae (1 species). The distribution pattern of these families across forest, agricultural fields, and fallow lands reflects the influence of vegetation structure, plant species composition, and microhabitat heterogeneity on butterfly assemblages (Fig. 2).

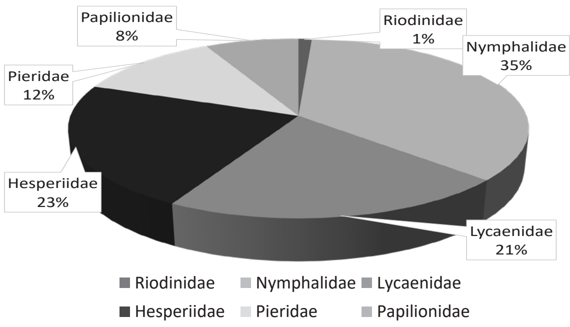

Fig. 2. Family wise diversity of butterflies

Ypthima huebneri, Euploea core, Ampittia dioscorides, Eurema hecabe, and *Mycalesis perseus* were the most abundant species in the study area. Majority of plant species belonging to the above mentioned genus are abundant in the study area. *Ampitta dioscorides* was another species present in high abundance, this could be attributed to the fact that *Cynodon dactylon* and *Oryza sativa* which are the main host-plants for this butterfly species are abundant in agricultural fields in the study area.

Table 1. Diversity indices for different habitats

Land use	No. of species	Shannon-Wiener Index (H)	Evenness (J)	Simpson's Index/ Dominance	Simpson's Index of diversity (1-D)	Simpson's Reciprocal Index (1/D)
Agriculture	54	3.12	0.78	0.058	0.942	17.245
Fallow land	49	3.37	0.87	0.042	0.958	23.618
Forest	68	3.49	0.83	0.041	0.959	24.231
Total	93	3.79	0.84	0.028	0.972	36.132

The highest representation was from Nymphalidae (33 species), followed by Lycaenidae (20 species), Hesperiidae (21 species), Pieridae (11 species), Papilionidae (7 species), and Riodinidae (1 species). The distribution pattern of these families across forest, agricultural fields, and fallow lands reflects the influence of vegetation structure, plant species composition, and microhabitat heterogeneity on butterfly assemblages.

The Shannon-Wiener Index (H') followed a similar gradient, with the highest diversity observed in forest (H' = 3.49), followed by fallow land (H' = 3.37) and agriculture (H' = 3.12). These values indicate generally high diversity across the landscape, with forest habitats providing the greatest structural complexity and microhabitat variation (Table. 1).

Evenness (J) values were consistently high across habitats (Table. 1), showing that species were fairly evenly distributed. Fallow land showed the highest evenness (0.87), suggesting a relatively uniform distribution of species typically associated with early-successional vegetation. Dominance, measured using Simpson's Index (D), was highest in agriculture (0.058), reflecting the influence of regular disturbance and the prevalence of a few tolerant species. Forest (D = 0.041) and fallow land (D = 0.042) showed lower dominance, indicating higher ecological balance and reduced skewness in species abundance. The overall values indicate a highly diverse and ecologically balanced butterfly community across the periphery of Satkosia Tiger Reserve. The checklist of butterflies recorded from Satkosia Tiger Reserve, Angul, Odisha has been presented in Table. 2.

The forested (68) patches around Satkosia Tiger Reserve showed the highest diversity, particularly dominated by Nymphalidae and Lycaenidae. This is because forest habitats provide multi-layered canopy structure (trees, shrubs, herbs, climbers), forest edges and ecotones, shade-tolerant nectar plants, fruiting resources, higher humidity and microclimatic stability and more importantly the presence of host plants for forest specialists. The high richness of these families indicates that forest patches maintain good ecological quality, structural heterogeneity, and continuous vegetation cover required for forest-dependent species. Agricultural fields dominated by crops, bund vegetation, weeds, and scattered trees supported a different community of butterflies, especially Pieridae and Hesperiidae. Open sunny conditions, abundance of herbaceous weeds, Seasonal crops, agriculture edges supporting grasses and legumes. Agricultural landscapes, despite being modified, act as semi-natural habitats that sustain generalist and open-habitat butterflies. Species richness (54) here reflects availability of herbaceous vegetation rather than woody plant structure. *Ampittia dioscorides* and *Junonia almanac* (99) emerged as the most abundant species. The Bush Hopper is known to prefer grassy patches, weedy edges commonly found along agricultural bunds and small water channels, which explains its dominance and frequently seen in crop fields, fallow edges, and open patches. Its preference for disturbed habitats makes agriculture fields ideal. *Ypthima huebneri* (46), *Mycalesis perseus* (45) *Eurema hecabe* (43) are other notable species found in the agriculture dominated patches. The abundance pattern reflects the structural openness and herbaceous vegetation diversity. The dominance of grassland-associated and disturbance-tolerant species highlights how agriculture acts as a productive yet dynamic habitat supporting high butterfly activity. Fallow lands act as transition habitats, and serve as important buffer zones between forest and agriculture, enhancing landscape-level connectivity. Fallow or abandoned agricultural lands had a mixture of early successional weeds, grasses, and shrubs, attracting nectar-feeding generalists, Sunlight-exposed open patches, dominated by fast-growing weeds (*Tridax* spp., *Chromolaena* sp.) and high abundance of herbaceous flora are well supported to habitat generalist and specialist species.

The highest abundance recorded in this habitat was for *Catopsilia pomona* (38) and *Eurema hecabe* (38) and known to prefer sunlit open areas where host plants such as Cassia, Senna, and various legumes thrive naturally in abandoned or seasonally fallow farmlands. Their dominance indicates that the fallow landscape is rich in herbaceous vegetation and early-successional plant species that support larval development and adult foraging. Another notable species was *Ypthima huebneri, Papilio polytes* and *Acraea terpsicore,* reflecting the presence of weedy herbaceous flora. The presence of species is further reinforcing the role of fallow land as a stable habitat for early-successional and disturbance-tolerant butterfly species. Results show that butterfly diversity increases with heterogeneous vegetation structure, Forest habitats support specialists, while open and fallow habitats support generalists together forming a complementary landscape mosaic that enhances overall richness.

Table 2. Checklist of butterflies recorded from Satkosia Tiger Reserve, Angul, Odisha

Sl. No	Family	Common name	Scientific name
1	Hesperiidae	Bush hopper	*Ampittia dioscorides* (Fabricius, 1793)
2	Hesperiidae	Brown awl	*Badamia exclamationis* (Fabricius, 1775)
3	Hesperiidae	Rice swift	*Borbo cinnara* (Wallace, 1866)
4	Hesperiidae	Golden angle	*Caprona ransonnettii* (R. Felder, 1868)
5	Hesperiidae	Plain palm-dart	*Cephrenes acalle* (Höpffer, 1874)
6	Hesperiidae	Tricolour pied flat	*Coladenia indrani* (Moore, 1866)
7	Hesperiidae	Bispot banded ace	*Halpe porus* (Mabille, 1877)
8	Hesperiidae	Common banded awl	*Hasora chromus* (Cramer, 1780)
9	Hesperiidae	Chestnut bob	*Iambrix salsala* (Moore, 1866)
10	Hesperiidae	Common branded redeye	*Matapa aria* (Moore, 1866)
11	Hesperiidae	Restricted demon	*Notocrypta curvifascia* (C. & R. Felder, 1862)
12	Hesperiidae	Straight swift	*Parnara guttatus* (Bremer & Grey, 1852)
13	Hesperiidae	Small branded swift	*Pelopidas mathias* (Fabricius, 1798)

14	Hesperiidae	Large branded swift	*Pelopidas subochracea* (Moore, 1878)
15	Hesperiidae	Common small flat	*Sarangesa dasahara* (Moore, 1866)
16	Hesperiidae	Asian grizzled skipper	*Spialia galba* (Fabricius, 1793)
17	Hesperiidae	Oriental palm bob	*Suastus gremius* (Fabricius, 1798)
18	Hesperiidae	Grey-veined grass dart	*Taractrocera maevius* (Fabricius, 1793)
19	Hesperiidae	Dark palm-dart	*Telicota bambusae* (Moore, 1878)
20	Hesperiidae	Pale palm dart	*Telicota colon* (Fabricius, 1775)
21	Hesperiidae	Grass demon	*Udaspes folus* (Cramer, 1775)
22	Lycaenidae	Common hedge blue	*Acytolepis puspa* (Horsfield, 1828)
23	Lycaenidae	Common ciliate blue	*Anthene emolus* (Godart, 1824)
24	Lycaenidae	Indian oakblue	*Arhopala atrax* (Hewitson, 1862)
25	Lycaenidae	Angled castor	*Ariadne ariadne* (Linnaeus, 1763)
26	Lycaenidae	Angled pierrot	*Caleta decidia* (Hewitson, 1876)
27	Lycaenidae	Common pierrot	*Castalius rosimon* (Fabricius, 1775)
28	Lycaenidae	Forget-me-not	*Catochrysops strabo* (Fabricius, 1793)
29	Lycaenidae	Lime blue	*Chilades lajus* (Stoll, 1780)
30	Lycaenidae	Plains cupid	*Chilades pandava* (Horsfield, 1829)
31	Lycaenidae	Common silverline	*Cigaritis vulcanus* (Fabricius, 1775)
32	Lycaenidae	Gram blue	*Euchrysops cnejus* (Fabricius, 1798)
33	Lycaenidae	Black-spotted grass jewel	*Freyeria putli* (Kollar, 1844)
34	Lycaenidae	Orchid tit	*Hypolycaena othona* (Hewitson, 1865)
35	Lycaenidae	Common cerulean	*Jamides celeno* (Cramer, 1775)
36	Lycaenidae	Yamfly	*Loxura atymnus* (Stoll, 1780)
37	Lycaenidae	Dingy blue	*Petrelaea dana* (de Nicéville, 1884)
38	Lycaenidae	Pale grass blue	*Pseudozizeeria maha* (Kollar, 1844)
39	Lycaenidae	Monkey puzzle	*Rathinda amor* (Fabricius, 1775)
40	Nymphalidae	Common acacia blue	*Surendra quercetorum* (Moore, 1858)
41	Nymphalidae	Striped pierrot	*Tarucus nara* (Kollar, 1848)
42	Nymphalidae	Lesser grass blue	*Zizina otis* (Fabricius, 1787)
43	Nymphalidae	Tawny coster	*Acraea terpsicore* (Linnaeus, 1758)
44	Nymphalidae	Common castor	*Ariadne merione* (Cramer, 1777)
45	Nymphalidae	Anomalous nawab	*Charaxes agrarius* (Swinhoe, (1887)
46	Nymphalidae	Black rajah	*Charaxes solon* (Fabricius, 1793)
47	Nymphalidae	Plain tiger	*Danaus chrysippu*s (Linnaeus, 1758)
48	Nymphalidae	Striped tiger	*Danaus genutia* (Cramer, 1779)
49	Nymphalidae	Common palmfly	*Elymnias hypermnestra* (Linnaeus, 1763)
50	Nymphalidae	Common crow	*Euploea core* (Cramer, 1780)
51	Nymphalidae	Common baron	*Euthalia aconthea* (Cramer, 1777)
52	Nymphalidae	Great eggfly	*Hypolimnas bolina* (Linnaeus, 1758)
53	Nymphalidae	Glassy tiger	*Ideopsis similis* (Linnaeus, 1758)

54	Nymphalidae	Peacock pansy	*Junonia almana* (Linnaeus, 1758)
55	Nymphalidae	Grey pansy	*Junonia atlites* (Linnaeus, 1763)
56	Nymphalidae	Yellow pansy	*Junonia hierta* (Fabricius, 1798)
57	Nymphalidae	Chocolate pansy	*Junonia iphita* (Cramer, 1779)
58	Nymphalidae	Lemon pansy	*Junonia lemonias* (Linnaeus, 1758)
59	Nymphalidae	Blue pansy	*Junonia orithya* (Linnaeus, 1758)
60	Nymphalidae	Orange oakleaf	*Kallima inachus* (Doyère, 1840)
61	Nymphalidae	Bamboo treebrown	*Lethe europa* (Fabricius, 1775)
62	Nymphalidae	Common evening brown	*Melanitis leda* (Linnaeus, 1758)
63	Nymphalidae	Dark evening brown	*Melanitis phedima* (Cramer, 1780)
64	Nymphalidae	Commander	*Moduza procris* (Cramer, 1777)
65	Nymphalidae	Small long brand bushbrown	*Mycalesis igilia* (Fruhstorfer, 1911)
66	Nymphalidae	Dark-brand bushbrown	*Mycalesis mineus* (Linnaeus, 1758)
67	Nymphalidae	Common bushbrown	*Mycalesis perseus* (Fabricius, 1775)
68	Nymphalidae	Common sailer	*Neptis hylas* (Linnaeus, 1758)
69	Nymphalidae	Common leopard	*Phalanta phalantha* (Drury, 1773)
70	Nymphalidae	Baronet	*Symphaedra nais* (Forster, 1771)
71	Nymphalidae	Grey count	*Tanaecia lepidea* (Butler, 1868)
72	Nymphalidae	Blue tiger	*Tirumala limniace* (Cramer, 1775)
73	Nymphalidae	Common five-ring	*Ypthima baldus* (Fabricius, 1775)
74	Nymphalidae	Common four-ring	*Ypthima huebneri* (Kirby, 1871)
75	Papilionidae	Common jay	*Graphium doson* (C. & R. Felder, 1864)
76	Papilionidae	Common rose	*Pachliopta aristolochiae* (Fabricius, 1775)
77	Papilionidae	Crimson rose	*Pachliopta hector* (Linnaeus, 1758)
78	Papilionidae	Lime swallowtail	*Papilio demoleus* (Linnaeus, 1758)
79	Papilionidae	Green-banded peacock	*Papilio palinurus* (Fabricius, 1787)
80	Papilionidae	Blue mormon	*Papilio polymnestor* (Cramer, 1775)
81	Papilionidae	Common mormon	*Papilio polytes* (Linnaeus, 1758)
82	Pieridae	Lemon emigrant	*Catopsilia pomona* (Fabricius, 1775)
83	Pieridae	Mottled emigrant	*Catopsilia pyranthe* (Linnaeus, 1758)
84	Pieridae	Indian jezebel	*Delias eucharis* (Drury, 1773)
85	Pieridae	Painted jezebel	*Delias hyparete* (Linnaeus, 1758)
86	Pieridae	One-spot grass yellow	*Eurema andersonii* (Moore, 1886)
87	Pieridae	Small grass yellow	*Eurema brigitta* (Stoll, 1780)
88	Pieridae	Common grass yellow	*Eurema hecabe* (Linnaeus, 1758)
89	Pieridae	Yellow orange-tip	*Ixias pyrene* (Linnaeus, 1764)
90	Pieridae	Psyche	*Leptosia nina* (Fabricius, 1793)
91	Pieridae	Dark wanderer	*Pareronia ceylanica* (C. & R. Felder, 1865)
92	Pieridae	Common wanderer	*Pareronia valeria* (Cramer, 1776)
93	Riodinidae	Double-banded judy	*Abisara bifasciata* (Moore, 1877)

CONCLUSION

The study area is a mosaic type of landscape with a variety of natural and man-made ecosystems. This ecosystem is rich in flora and fauna. Village level institutions, Van Suraksha Samiti (VSS) and Eco Development Committees (EDC) are committed to the sustainable use and conservation of these ecosystems. For the past few years, programs for the improvement of natural habitats have been continuously being carried out in this area. It directly impacted the floral and faunal diversity of the area and as a result, the number of species documented by the current study may be higher, requiring further study for understanding the symbiotic relations of flora and butterfly diversity which will not only be helpful for conservation of species but also will serve the overall ecosystem health.

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