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Biodiversity and ecosystem services associated to urban plantations in the municipalities of Mecheria and Naâma (southwest Algeria)

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Abstract. Surveys were carried out in the municipalities of Mecheria and Naâma (southwest Algeria) to identify the biodiversity of urban plantations and determine the ecosystem services related to these plantations.
The results obtained enabled us to inventory 29 species belonging to 26 genera and 20 families, of which the Oleaceae family was the largest in terms of number of species. The only biological form identified was phanerophytes. Of the 29 taxa recorded, non-native taxa predominated (13 cultivated species, 4 introduced species, 4 naturalized/introduced species). Taxa of spontaneous origin number 7 and only one species is considered problematic. In terms of ecosystem services, we counted 5 shade species, 15 aesthetic species, and 9 food species.

Keywords: biological form, non-native taxa, spontaneous taxa, shade species, aesthetic species, food species

1. Introduction

Cities are full of numerous planted or natural plant formations. These plant formations are represented by parks, public gardens, street trees, green spaces, etc. [1, 2]. In urban areas, trees contribute to air purification by sequestration of carbon dioxide [3], to the creation of a microclimate, to the natural balance, and to the attractiveness of the territory [4]. These advantages are attributed to the tree functions at the social, economic, and environmental levels [5], the importance of which is reflected by the ecosystem services [6]. In recent years, nature in the city has become one of the major themes addressed within the scientific community [7]. Cities must be planned in such a way as to improve the living environment of urban dwellers and make the city more pleasant [8].

In 2007, Algeria introduced a law on the maintenance, protection, and planning of green spaces, intending to improve the living environment of citizens, preserve human health, and maintain ecological and climatic balance. This law puts in place a "genuine policy" for the establishment of a network of green spaces, enabling the promotion of their extension in the urban environment, by making the introduction of green spaces, in all construction projects, an obligation that must be taken into account in public and private urban planning and architectural studies.

Furthermore, the notion of ecosystem service has become essential over the past ten years in the international biodiversity arenas [9]. It was publicized following a consultation of international experts between 2001 and 2005 known as the Millennium Ecosystem Assessment (MEA) [6]. This initiative marked the beginning of a new approach to biodiversity conservation policies based on the clarification of our dependencies on the proper functioning of ecosystems. By definition, ecosystem services are the conditions and processes through which natural ecosystems and the species that make them up sustain and fulfil human life [10]. The concept of ecosystem services encompasses the delivery, provision, production, protection, or maintenance of a set of goods and services that people perceive to be important [11, 12, 13].

Knowledge of the services provided by urban plantations to citizens and the types of species that provide them is necessary for the better integration of urban forestry into land-use planning. It is in this context that this research was carried out on the ecosystem services associated with urban plantations in the municipalities of Mecheria and Naâma (southwest Algeria).

2. Materials and methods

Study area

Two municipalities have been chosen to carry out this research. These are the municipalities of Mecheria and Naâma, which are considered the most important in terms of urban development in the province of Naâma (*Fig. 1*).

The municipality of Mecheria is located in the northeast of the province of Naâma, between 0°3' to 0°25' East longitude and 33°27' to 33°42' North latitude [14]. This municipality covers an area of 736.25 km^2 [15]. The municipality is in the form of a vast asymmetrical syncline; the axis of this syncline presents the high points of Djebel Antar and Anitar. It has approximately 109,991 inhabitants, which represents almost a third of the total population of the province of Naâma [16].

The municipality of Naâma covers an area of 2,482.5 km². It is located 30 kilometres south of the municipality of Mecheria, between latitude 33°16' North and longitude 0°19' West [16]. The Naâma region is based on a massif dating from the Upper Jurassic and extends over a gentle relief whose altitude varies between 1,200 and 1,500 m [17, 18]. The population in the municipality of Naâma is estimated at approximately 28,753 inhabitants. This represents almost 9% of the total population of the province of Naâma [16].

The two study areas are characterized by an average annual rainfall of around 194.5 mm/year (period: 1992–2021). These precipitations are irregular, weak, and stormy. The average annual temperature is 19.5 °C. The hottest month is July at 30.5 °C and the coldest is January at 7.5 °C [19].

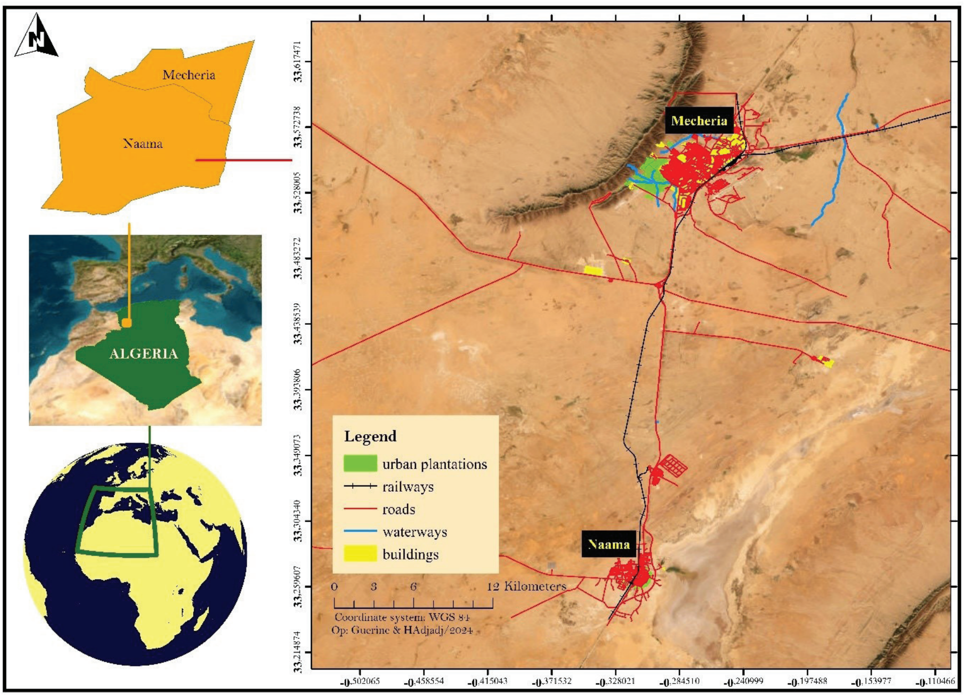

Figure 1. Localization of study zones

Methodology

The inventory of the horticultural flora of the study region was carried out during the year 2023. Main roads, green spaces, and public gardens were surveyed. The species encountered were photographed, and samples were collected for identification.

The identification was made by referring to [20], [21], [22], and [23]. The nomenclature is adjusted according to the synonymous index of [24]. The native or introduced status of the taxa listed refers to the North Africa database [25]. The life forms (or biological types) of the taxa observed are given according to [26].

Then, surveys were carried out among samples of residents of the two municipalities to understand the uses, as well as the services that urban plantations provide to populations (shading, aesthetic, medicinal, food…).

3. Results and discussions

Diversity of urban plantations

A total of 29 urban plant species belonging to 26 genera and 20 families were identified in public gardens, streets, and green spaces in the communes of Mecheria and Naâma (*Table 1*, *Fig. 2*). The Oleaceae family was the most important in terms of number of species, with a rate of 13.77% (4 species), followed by the Arecaceae family with 10.33% (3 species). The Cupressaceae, Fabaceae, Moraceae, and Myrtaceae families are represented by two species, i.e. a percentage of 6.90%. The Anacardiaceae, Elaeagnaceae, Salicaceae, Malvaceae, Pinaceae, Rutaceae, Punicaceae, Apocynaceae, Vitaceae, Celastraceae, Meliaceae, Casuarinaceae, Rosaceae, and Lamiaceae families are represented by just one species each (3.45%).

Table 1. List of identified species

Taxa	Families	Biological type	Native status	Ecosystem services
Cupressus sempervirens L.	Cupressaceae	Ph	Problematic	Aesthetics
Platycladus orientalis (L.) Franco		Ph	Cultivated	Aesthetics
Schinus molle L.	Anacardiaceae	Ph	Cultivated	Shadow

Taxa	**Families**	**Biological type**	**Native status**	**Ecosystem services**
Phoenix dactylifera L.	Arecaceae	Ph	Cultivated	Aesthetics
Washingtonia robusta H. Wendl		Ph	Cultivated	Aesthetics
Washingtoniafilifera (André) H. Wendl.		Ph	Cultivated	Aesthetics
L. igustrum ovalifolium Hassk	Oleaceae	Ph	Naturalized/ introduced	Aesthetics
L.igustrum japonicum Thunb		Ph	Naturalized/ introduced	Aesthetics
Fraxinus angustifolia Vahl		Ph	Spontaneous	Aesthetics
Olea europeae L.		Ph	Spontaneous	Food
Elaeagnus angustifolia L.	Elaeagnaceae	Ph	Spontaneous	Food
Populus nigra L.	Salicaceae	Ph	Introduced	Aesthetics
Brachychiton populneus (Schott & Endl.)	Malvaceae	Ph	Introduced	Aesthetics
Ceratonia siliqua L.	Fabaceae	Ph	Spontaneous	Food
Robinia pseudoacacia L.		Ph	Naturalized/ introduced	Aesthetics
Morus alba L.	Moraceae	Ph	Naturalized/ introduced	Food
Ficus carica L.		Ph	Cultivated	Food
Pinus halepensis Mill	Pinaceae	Ph	Spontaneous	Shadow
Eucalyptus globules L. abill.	Myrtaceae	Ph	Introduced	Shadow
Eucalyptus camaldulensis Dehnh.		Ph	Introduced	Shadow
Citrus limon (L.) Burm. f.	Rutaceae	Ph	Cultivated	Food
Punica granatum L.	Punicaceae	Ph	Cultivated	Food
Nerium oleander L.	Apocynaceae	Ph	Spontaneous	Aesthetics
Vitis vinifera L.	Vitaceae	Ph	Cultivated	Food
Euonymus japonicas L. f	Celastraceae	Ph	Cultivated	Aesthetics
Melia azedarah L.	Meliaceae	Ph	Cultivated	Aesthetics

Taxa	Families	Biological type	Native status	Ecosystem services
Casuarina equisetifolia L.	Casuarinaceae	Ph	Cultivated	Shadow
Pyrus communis L.	Rosaceae	Ph	Cultivated	Food
Rosmarinus officinalis L.	Lamiaceae	Ph	Spontaneous	Aesthetics

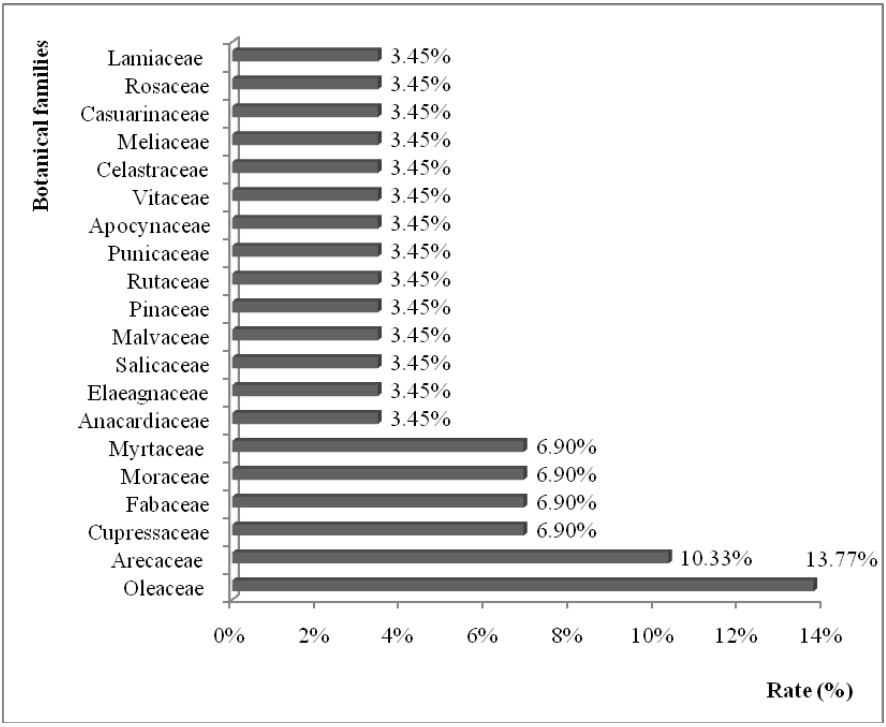

Figure 2. Rate of number of species by botanical families

Biological form

The only biological form determined was phanerophytes (29 taxa, i.e. 100%). The floristic composition made it possible to distinguish several plant groupings:

- forest taxa, the most dominant group, essentially represented by: *Cupressus sempervirens* L., *Platycladus orientalis* (L.) Franco, *Schinus molle* L., *Fraxinus angustifolia* Vahl, *Olea europaea* L., *Ceratonia siliqua* L., *Populus nigra* L., *Pinus halepensis* Mill, *Eucalyptus globules* Labill, *Eucalyptus camaldulensis* Dehnh, *Casuarina equisetifolia* L., *Rosmarinus officinalis* L.;

- fruit tree, represented by: *Phoenix dactylifera* L., *Washingtonia robusta* H. Wendl, *Washingtonia filifera* (André) H. Wendl, *Elaeagnus angustifolia* L., *Morus alba* L., *Ficus carica* L., *Citrus limon* (L.) Burm. f., *Punica granatum* L., *Vitis vinifera* L., *Pyrus communis* L.;
- ornamental tree, represented by: *Ligustrum ovalifolium* Hassk, *Ligustrum japonicum* Thunb. *Brachychiton populneus* (Schott & Endl.), *Robinia pseudoacacia* L., *Nerium oleander* L., *Euonymus japonicas* L. f., *Melia azedarah* L.

Native status

Of the 29 taxa recorded, non-native taxa predominate in the flora studied: 13 cultivated species, i.e. 44.83%; 4 introduced species, i.e. 13.79%; 4 naturalized/introduced species, i.e. 13.79% (*Fig. 3*, *Table 1*).

Taxa whose presence is problematic are represented by a single species (*Cupressus sempervirens* L.) (3.45%).

Taxa of spontaneous origin number 7 (24.14%): *Fraxinus angustifolia* Vahl, *Olea europeae* L., *Elaeagnus angustifolia* L., *Ceratonia siliqua* L., *Pinus halepensis* Mill, *Nerium oleander* L., *Rosmarinus officinalis* L.

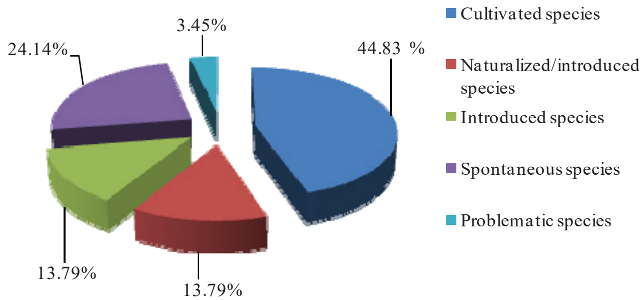

Figure 3. Native status of identified species

Ecosystem services

Shade species

This category is represented by 4 families, 4 genera, and 5 species (*Table 1*). The Myrtaceae family is the most represented, with 2 species. The other families are represented by a single species per family. These are generally species with well-developed symmetrical crowns and a large projection surface.

Aesthetic species

This category comprises 10 families, 13 genera, and 15 species (*Table 1*). The most dominant families are Arecaceae and Oleaceae with 3 species each and Cupressaceae with 2 species. The remaining families have just one species per family.

These species are characterized by their decorative habit and crowns. Examples include *Platycladus orientalis* (L.) Franco, *Washingtonia robusta* H. Wendl, *Ligustrumo valifolium* Hassk, *Ligustrum japonicum* Thunb., and *Fraxinus angustifolia* Vahl (*Table 1*).

Food species

9 species belonging to 8 families and 9 genera are included in this category. All these families are represented by a single species, except the Moraceae family, which has 2 species (*Table 1*).

The food species identified are either fruit trees, such as *Ficus carica* L., *Punica granatum* L., *Vitis vinifera* L., or *Pyrus communis* L., or forest trees offering edible fruit such as *Ceratonia siliqua* L. or *Olea europeae* L.

Figure 4. Photos of some identified species (a: *Brachychiton populneus* (Schott & Endl.); b: *Populus nigra* L.; c: *Pinus halepensis* Mill; d: *Euonymus japonicus* L.; e: *Morus alba* L.; f: *Phoenix dactylifera* L.)

4. Conclusions

The concept of urban forestry is beginning to gain ground as a way of extending the urban fabric. This concept is very little developed in Algeria's highland cities.

This first assessment focused on the biodiversity of urban plants in the communes of Mecheria and Naâma (southwest Algeria) and on their potential for producing social services. Through this first contribution, we have identified 29 species belonging to 26 genera and 20 families. These species provide shade for the people and are both aesthetic and food species. The majority of the species inventoried in streets and green spaces are introduced. Therefore, it would be recommended to consider mechanisms for integrating native species into these spaces.

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The authors would like to thank Mr ZAIR Mustapha, former expert in the forests conservation of Naâma (Algeria) and Professor Mohammed IBN TATTOU (Morocco) for their contribution to this work.

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Joint management policy as a tool for GIAHS conservation: The Ghout system in the Souf oasis (Algerian Sahara)

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Abstract. The Ghout system is a traditional agricultural system classified as a World Agricultural Heritage (GIAHS) by the FOA since 2005. This paper discusses the joint management principle as a tool to preserve the Ghout system as an agricultural landscape in the Souf oasis (Algerian Sahara). The Ghout system has been based on mono-management by the local farmers since it was created in the 15th century, who managed it well all this time. However, this GIAHS suffers from many difficulties, which have led to the demise of a significant part of it. Today, moving to the principle of joint management has become a necessity, not an option. However, besides the local farmers, this principle depends on several stakeholders' involvement in managing this traditional agricultural system. Also, this paper provides a roadmap to help make this proposed principle a success.

Keywords: Ghout, joint management, conservation, Souf oasis, GIAHS, Algeria

1. Introduction

Agriculture is the most important human activity that is closely associated with nature. The operational units of this activity are called agricultural systems, which emerge and develop over time in a socioeconomic and cultural context [4]. Whelan [59] defined the farming system as the significant and constant arrangement of farming activities, the practices of which correspond with the biological, physical, and socio-economic environment in response to the local community's needs and adjustments to its changing and limiting resources. Traditional farming systems resulted from centuries of biological and cultural exchanges between humankind and the surrounding environment [46]. Furthermore, it is characterized by high efficiency in managing nutrients, water, soil, and biological resources [5].

The Food and Agriculture Organization of the United Nations (FAO) has defined the Globally Important Agricultural Heritage Systems (GIAHS) as "remarkable land-use systems and landscapes which are rich in globally significant biological diversity evolving from the co-adaptation of a community with its environment and its needs and aspirations for sustainable development" [6, 34]. The global change affects entire agricultural systems, in which regard, the GIAHS sites are not impervious to this change either [32].

The FAO, jointly with the Global Environment Facility (GEF) and the United Nations Development Programme (UNDP), started the policy of the dynamic conservation and sustainable management of these traditional agricultural heritage systems in 2002 [49, 62]. However, the dynamic conservation and adaptive management of these farming systems have become critical issues [64], mainly because of their abandonment worldwide [47].

At the beginning of the twenty-first century, GIAHS had become a hotspot for scientific research because of its rapidly increasing number of sites [64]. In addition, this heritage has frequently been offered in recent years as a depot of lessons to be learned for future, more sustainable agriculture [17]. Unfortunately, these traditional agricultural systems are under continuous pressure from various sides such as socioeconomic changes, climate change, and increased competition for natural resources worldwide [3]. For example, the new agricultural paradigm focused on mechanization and agricultural intensification has detracted from the traditional agroecosystem, so much so that the latter is in danger of disappearing [6]. So, the disappearance of traditional agricultural systems due to environmental overprotective and changed socioeconomic conditions seriously threatens biological and cultural diversity worldwide [41].

The GIAHS plays a pivotal role in natural balance, especially in the arid environment. The Ghout system is an example of these traditional agricultural systems; the latter is located in an arid environment (Souf oasis, Algeria) (*Fig. 1*) and has been classified by the FAO as a GIAHS since 2005 [9]. Many studies indicate that a significant part of this GIAHS has disappeared (*Fig. 2*), and what remains of it is also threatened with extinction due to the many difficulties it suffers from [25, 27, 28, 30]. So, discovering how to protect GIAHS effectively is important for scientific research and key for sustainable development [39]. This paper discusses the failure causes of the mono-management principle in managing and preserving the Ghout system in the Souf oasis (Algerian Sahara). In addition, it suggests the transfer to the joint management principle as a tool to safeguard this GIAHS. Furthermore, it will discuss some factors that could contribute to the success of this new type of management.

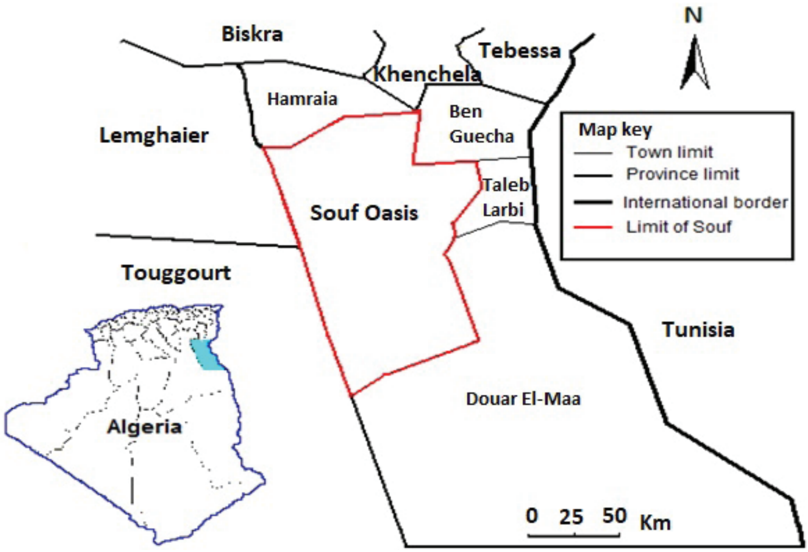

Figure 1. Location of the Souf oasis

Figure 2. A Ghout system a): in a good condition, b): in a deteriorated condition

2. The Ghout system as a GIAHS

Traditional knowledge accumulated among local communities is holistic, encompassing many fields of scientific knowledge such as hydrology, soils, climate, animals, and plants [42]. This traditional knowledge was the reason for establishing and continuing many agricultural systems that were in harmony with the environment for centuries.

The first inhabitants succeeded in settling in the Souf oasis by practising agriculture through the Ghout system. Historical studies indicate that the establishment of this system dates back to the 15th century when the first Ghout was accomplished in the village of Zgum [26]. In the first step, the farmer chooses an adequate place for his new Ghout, of course, strictly respecting the agricultural laws adopted by the community of local farmers [45, 57]. The drilling process begins vertically with simple and primitive methods until it reaches the aquifer. Next, the farmer prepares the first palm tree for planting, in which the roots are in direct contact with moist soil. After that, the farmer continues the horizontal digging to expand the Ghout surface and continues planting date palm trees [29]. This process may take several years, depending on the geographical location, groundwater depth, and the Ghout surface.

The adopted method enables young date palms to benefit from self-watering without interference from the farmer [37]. However, the farmer is still in permanent combat with sand encroachment. In the spring and autumn, wind leads to the burial of the Ghout edges, as the farmer is periodically forced to re-raise it [22]. The date palm trees occupy the higher floor of the Ghout, which creates a suitable microclimate compared to the harsh external climate. This microclimate allows the farmer to cultivate several fruit trees, such as pomegranates, grapes, lemons, and apples, which occupy the middle floor of the Ghout [29].

On the lower floor, the farmers cultivate various vegetables and fruits such as tomatoes, peppers, eggplant, spinach, onions, and watermelon. Moreover, in the northern part of the Souf oasis, the farmers cultivate tobacco as an industrial crop [48]. Because the crops of the lower and middle floors cannot directly benefit from the phreatic water table, such as palm trees, farmers irrigate them manually through a traditional system for water extraction called, in vernacular terms, Khottara [14]. This agricultural system was combined with the practice of permanent and seasonal crops. Furthermore, it ensured food security during the famine that affected the Algerian Sahara during colonization.

3. Mono-management model: Its development and failing factors

The mono-management by local farmers has succeeded in expanding the Souf oasis, as Khezzani and Bouchemal [28] reported that the number of Ghouts that have been accomplished has reached about 9,800 units. In the past, farmers used to view the Ghout as the only way to ensure food security for their family. However, recently, it has become a way to make a quick profit. In the first case, farmers cannot achieve food security without preserving the Ghout. In the second case, farmers can achieve food security even in the absence of the Ghout.

Until the 1950s, the Ghout was the main agricultural food production system in the Souf oasis. The development of groundwater extraction systems catalysed the emergence of a farming sector parallel to the Ghout system. Farmers no longer need to dig a big hole to reach the groundwater but can now plant palm trees directly on the surface and water them with the help of pumps [25]. The discovery of new fossil aquifers in the Algerian Sahara announced the birth of a new agricultural revolution [13]. This agrarian revolution was distinctive in the Souf oasis, as new and varied crops were introduced such as potatoes, olives, peanuts, and many other vegetables [14, 31].

Now, farmers have many options; their choices are controlled by the economic feasibility of the agricultural project. Thus, they can move from one crop to another according to market requirements. For example, some farmers left their Ghouts and oriented towards cultivating new crops; others buried the Ghouts and cut their palms to level the ground and installed the pivot system to irrigate the new crops of potatoes [23]. Still others left the agricultural sector permanently to invest in other activities that guaranteed them a profitable return. This point of view agrees with what was mentioned by Prus et al. [41], who likened this behaviour to reverse migration due to the low economic viability of traditional farming.

The demographic growth witnessed by the oasis led to an increase in the demand for residential real estate, especially in areas adjacent to major population centres. As a result, many farmers buried their fields and converted them into buildable lands by filling them up, dividing them, and selling them as housing lots. Of course, the high and attractive prices offered to farmers catalysed this process [24]. Today, it is clear that the local farmer is the only person who determines the fate of the Ghout according to the individual interests. Furthermore, farmers have never considered the Ghout a world agricultural heritage. Still, the main driver of his behaviour is the economic approach or the arithmetic process that means profit and loss for what will result from their exploitation of the Ghout. This point of view is confirmed by a recent study by Khezzani et al. [30], which reported that only 12.3% of local farmers know that their Ghouts system has become a GIAHS although classified under FAO since 2005.

In conclusion, in the past, the mono-management policy applied by the local farmers was a helpful factor in developing the Ghout system; still, farmers alone can no longer guarantee the survival of this heritage. On the contrary, their behaviours have become harmful and destructive to the Ghout system. This critical situation quickly calls for the intervention of other parties to save what remains of this agricultural world heritage.

4. Joint management model as an alternative tool to preserve the Ghout system

A main challenge in traditional agricultural systems is to develop policies that promote socioeconomic development while at the same time safeguarding ecosystem services, biodiversity, and human values [18]. The FAO programme related to the globally important agricultural heritage systems (GIAHS) focuses on preserving the agricultural heritage system and applying the principle of dynamic conservation to assure food security for local communities and promote rural development [43]. Prus et al. [41] state that any endeavour to preserve GIAHS sites by freezing them in time would surely lead to their demise and weaken the rural communities. So, Daugstad et al. [15] and Chunjiang et al. [12] assumed the system of active agriculture, which means a production system founded on the economic results of food production, as the most sustainable strategy to protect traditional agricultural heritage and other environmental values.

This discussion clearly shows that the joint management policy is optimal for applying the dynamic conservation principle. After classifying the Ghout system as a world heritage, the local authorities in the Souf oasis were supposed to take the initiative to adopt the principle of joint management, but this did not happen for several reasons. Perhaps the most important one is the lack of a clear development policy to manage this agricultural heritage and/or that all the attention was directed to the modern agricultural sector [26, 30]. Many studies have confirmed that the joint management principle or, rather, the participation of multi-stakeholders has a positive effect on dynamic conservation, and it has been widely incorporated into sustainable landscape management [51, 58]. For example, China has made remarkable progress in managing and preserving agricultural heritage sites, mainly due to the policy that adopts the participation of multi-stakeholders [38, 61].

5. The actors and their role in the joint management model

The proposed joint management model focuses on three actors; the first is in the foreground, and the other two are in the background.

– The first and foremost actors are the local farmers and their families.

– The second actors are the local authorities, such as the agricultural services directorate in the first range and then the directorates of tourism, environment, and forest.

– The third actors are the academic researchers.

A. The role of academic researchers

The role of academic researchers is to carry out research that has a direct or indirect relationship with agricultural heritage. The main objective of this research is to make farming through the Ghout system a distinct and economically profitable activity for local farmers that can withstand and compete against the encroachment of other crops. Subsequently, researchers share the results of their research with politicians, decision makers, and policymakers alike. In this context, Qingwen [43] confirms that working within the main research areas directly related to heritage is not sufficient for the success of the preservation process. Indeed, it must extend to other disciplines such as sociology, history, geography, economics, management sciences, and other necessary subjects.

B. The role of administrative departments and policymakers

In the light of the recommendations made by the academic research bodies, the administrative departments can draw up the appropriate development policy that enables the maintenance and operation of the Ghout system on sustainable development foundations. For example, local authorities should create additional activities that accompany agriculture, which generate additive financial income for farmers and their families.

C. The role of the farmer

Shen et al. [49] focus on the influential role of local farmers in managing and protecting the agricultural heritage and support for rural communities. So, the local farmer will be the central hub and operator of the Ghout system in the joint management model.

6. The factors promoting the success of the joint management model (master plan)

The joint management of the Ghout system is not just administrative decisions issued by local authorities and implemented by farmers; instead, it is an accurate, complex, and multilateral model of preservation joined by farmers, academic researchers, and administrative authorities. The role of each actor is complementary to the others and cannot conflict with them. In the following paragraphs, we will try to lay out a master plan for the success of the joint management model.

A. The accomplishment of a database for GIAHS in the Souf oasis

From a practical point of view, the protection process cannot be materialized without the permanent and adequate follow-up of agricultural heritage status (Ghouts) [24]. Therefore, a database should be quickly established for the traditional agricultural sector. This database would contain all the necessary information such as inventory numbers of existing Ghouts in terms of location, surface, and the number of palms, productivity (quality and quantity); the age of date palm trees, legal status, as well as the identification of property type (collectively or individually). The availability of this vital information with permanent updates will enable the optimal management of this heritage, particularly regarding property transfers resulting from the sale and the purchase or conversion of these Ghouts to lands dedicated to construction or establishing other commercial activities.

B. The privacy of the traditional sector

The Ministry of Agriculture is the main authority responsible for managing the agricultural sector in the country. However, the laws issued by it are largely compatible with the modern agricultural sector, while they are less suitable for the traditional agricultural sector because there are fundamental differences between the two sectors, especially after classifying the latter as a GIAHS [24]. Perhaps this behaviour is explained by the significant contribution of the modern agricultural sector in ensuring food security compared to the traditional sector [26]. Therefore, the specificity of the traditional agricultural sector must be considered by enacting laws appropriate to the state of this heritage.

C. Solving some local problems related to the traditional agricultural sector

The traditional agricultural system in the Souf oasis suffered from many problems, which were the main reason for its abandonment by the local farmers. Perhaps the most critical problems are the disturbances related to the phreatic aquifer [28] and the urban sprawl, especially on the border of urban areas [1, 24]. Furthermore, the expansion of the modern agricultural sector at the expense of the traditional one is another problem; its impact is similar to the urban sprawl, mainly due to the interest of the local authorities in the modern agricultural sector compared to the traditional one [25].

The local authorities should urge the adoption of a plan aimed to solve these problems, which firstly contributed to the deterioration of the agricultural heritage and, secondly, stood in the way of the renewal process. Directing urban expansion in line with the status of the traditional sector is one of the axes that can be worked on; a recent study by Khezzani and Bouchemal [27] presented several solutions and techniques to deal with water table fluctuations.

D. Making the traditional agricultural sector economically profitable

The conservation of the GIAHS sites is highly relevant not only for their natural biodiversity but also for the sustainable provision of endogenous goods, the very high quality of food and services, and the quality of life different from those practised in large cities [35]. Zhang et al. [63] believe improving farmers' income from traditional agricultural activities is a practical approach to GIAHS conservation policy. So, this approach will make the traditional agricultural sector economically profitable, which is the essence of joint management and a major challenge for local authorities. This process automatically allows local farmers to cling to the traditional sector; through this element, activating the dynamic conservation mechanism becomes possible. Currently, there are two areas in which we can intervene and implement some reforms, which are tourism and organic farming.

Developing the ecotourism sector

In most cases, traditional agriculture alone cannot provide sufficient income to local farmers and their families [46, 60]. Perhaps the best solution is to work on improving and diversifying their income. Pillay and Rogerson [40] believe that using natural resources, such as traditional agriculture landscapes, in tourism supports sustainable rural development and promotes the integration of agriculture and tourism. Many studies worldwide confirm the importance of the GIAHS as a tourist attraction factor [10, 16, 19, 36, 52–56, 60], where many tourists favour visiting rural areas and sharing the rural lifestyle with local communities [21].

Although the Ghout system as an agricultural landscape has many ingredients that make it a tourist resort by excellence, touristic activities related to traditional farming are currently absent in the study area. It is worth noting that this type of tourism was at the height of its activity 30 years ago, when the oasis annually received a considerable number of tourist groups, especially from European countries. To restore this essential activity, experts in the tourism sector should adopt a programme. These tasks fall on the shoulders of the provincial tourism directorate in the first place.

Perhaps the intangible heritage and cultural background are the elements that can be associated with tourism activities. The study by Alhamidi et al. [4] confirmed that the cultural background was the cause of the sustainability of the traditional farming system in the Ghouta oasis, Syria. Also, Chen et al. [11] reported that the quality of life in one Japanese rural community improved after introducing some ecotourism activities although the economic benefits were marginal to most host households.

Introducing the Ghout system as a pioneer in organic farming

Given its positive environmental impact, organic farming is vital for ensuring sustainability and shifting to a green economy [2]. Nowadays, organic farming is getting more interest worldwide [20] because it can contribute to mitigating the global warming effect through its ability to sequester carbon in the soil [33]. It also effectively controls pollution [8] and promotes public health [7]. Food production through the Ghout system has many advantages that we do not find in other local production systems.

In this system, local farmers do not use just any pesticide or chemical fertilizer, but they fertilize the soil in a natural, organic manner (camel droppings) [26]. Although organic farming produces less amount of crops than conventional agriculture, it is more lucrative, environmentally friendly, and delivers an equal amount of or even more nutritious foods with less pesticide residue [44, 50].

Food production through the Ghout system should be valued and supported. It can also generate significant income to the farmers if it is introduced properly and managed well. This point of view is consistent with what was reported by Zhang et al. [63]. So, by introducing this method of food production to producers and consumers, the traditional agricultural system will be able to withstand the competition of modern farming systems. It is locally recognized that the dates produced traditionally (Ghout system) are distinguished by their large size, good taste, and long storage period. Unfortunately, there are no academic studies that prove these observations.

Due to globalization and changes in agricultural and production systems, agricultural heritage needs, more than ever before, a new approach and a wise policy to manage and preserve it. Obviously, conserving traditional farming systems cannot be accomplished in isolation from the local communities' traditional knowledge, culture, and social organization. However, the joint management principle of GIAHS will be part of this policy.

7. Conclusions

The Ghout is a traditional agricultural system located in the Souf oasis (Algerian Sahara) and has been classified as a GIAHS by the FAO since 2005. The Ghout system has been based on mono-management by the local farmers since it was created in the 15th century. The local farmers alone managed this system for several centuries. However, the socioeconomic and land-use changes in the oasis system since the second half of the 20th century have made the mono-management model impotent and unable to keep pace with the new conditions. This study proposes a joint management model as a tool to activate the dynamic conservation and sustainable management of this traditional agricultural system, including local farmers, administrative authorities, and academic researchers. However, this new management model needs several reforms, which together aim to make the traditional agricultural system economically profitable. Politicians and decision makers can use the results of this study to formulate a dynamic conservation policy for this local agricultural heritage.

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Breeding and conservation of the parasitoid *Psyttalia concolor* (Hymenoptera: Braconidae) to control the olive fruit fly *Bactrocera oleae* (Diptera: Tephritidae) and protect olive crops

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Abstract. Our work involves the biological control of the olive fly *Bactrocera oleae*, using the endoparasitoid *Psyttalia concolor*, which develops within the olive fly larvae. We studied the development stages of the host, and the emergence of adults in parasitoid rearing and discussed the contribution of this information to optimize production. The biological control methods require a significant investment in optimizing insect rearing. Our study describes breeding procedures for the parasitoid and its host *Bactrocera oleae*. This is still insufficient to reduce the pest and minimize its damage, achieving integrated management without applying other control techniques or using pesticide treatments.

Keywords: pest, damage, factor, olive, host, pesticide

1. Introduction

The olive fruit fly *Bactrocera oleae* is the main pest of the olive tree and one of the factors hampering olive production. The damage caused by this pest is extensive and varied, resulting in premature fruit drop, direct destruction of the pulp by the larvae, and reduced olive oil quality due to increased acidity [1]. Integrated pest management is defined as the process of controlling harmful organisms using a set of methods that meet economic, ecological, and ecotoxicological requirements, giving priority to actions that promote the natural control of crop pests and respecting economic intervention thresholds [2]. Optimal integration of olive fruit fly control techniques cannot be achieved without an understanding of their population biology and in particular their dynamics [3]. Until now, most information on the population fluctuations of these insects has been based on adult trapping. However, these data are only of relative importance and reliability, as the adults caught represent just a fraction of the population [4]. The olive fruit fly is a harmful pest, present throughout the Mediterranean countries, and efforts have been made to specify the main parameters to assess the damage caused by the pest [5]. The olive fruit fly and its parasitoids have been studied only slightly in Algeria despite their significant impact on olive products. Its parasitoids are divided into four species of Chalcidian ectoparasites with a wide distribution range and one Braconidae endoparasite originally from North Africa only. However, the most common ectoparasitic ones are *Eupelmus urozonus* and *Pnigalio mediterraneus*. It intrudes preferentially to parasitize third-stage larvae. Biological control also includes using other organisms or their products to prevent and minimize damage to plant production caused by pests [6]. At present, biological control is the method most favoured in research programmes, given its economic and agro-environmental benefits in maintaining a bio-ecological balance [7]. Most parasitoids prefer the third larval stage of *B. oleae* as a host; *Psyttalia (Opius) concolor* can parasitize all larval stages; *Eupelmus urozonus* can also lay eggs inside pupae [8]. Biological control uses living organisms to reduce the population levels of harmful organisms. The latter are responsible for many biological control successes and play an important role in natural ecosystems [9]. Biological control involves the use of an auxiliary parasitoid, predator, or pathogen to manage a targeted pest species. In our case, we are talking about classical biological control, as we have introduced a parasitoid to control a targeted pest species. *Psyttalia concolor* was the ideal parasitoid for the olive fruit fly in the Biskra region, due to its well-studied biology and parasitism. It is an important natural enemy against Tephritidae and is an endoparasitoid species, meaning that females lay their eggs inside their host, which continues to live throughout the first part of the parasitoid larvae development. It is a solitary parasitoid, with a single larva able at best to develop in a host. As with any biological control programme aimed at introducing an auxiliary organism into a new territory, several measures were required to comply with phytosanitary standards and risks. From the long series of trials and errors that make up the history of biological control, remarkable successes and promising achievements have been made in economic, environmental, and agricultural terms, particularly following the successful use of various biological control agents [10].

In biological control, the parasitoid must reduce the pest population to an acceptable level and maintain a consistently low density to prevent future pest reproduction. *Psyttalia concolor* has been introduced in many parts of the world to control the olive fruit fly *Bactrocera oleae*. In its native range (North Africa and the Near East), *Opius concolor* can generate parasitism rates of up to 60% on the olive fruit fly. Attempts were made to use this parasitoid as a biological control agent against *B. oleae*, but without real success, the challenges stemming from the difficulty of effectively reproducing this parasite in natural and controlled environments and the unpredictability of the results of this biological control. Thus, achieving high parasitism rates of *Psyttalia concolor* remains a goal that needs intensive research [11].

The use of integrated pest management (IPM) has often produced good results; however, the extension of these methods is still limited due to the complexity of the biological control agents [12].

Depending on the method of use, there are three main methods of biological control: introduction, augmentation, and conservation [13].

2. Materials and methods

We sampled olive fruits infested with the larvae and pupae of the olive fruit fly *Bactrocera oleae* in the olive grove.

Breeding

The preservation and transport of fruit found in the olive orchards required the use of plastic bags and plastic Petri dishes for the collection of olive fruit fly larvae and pupae. A qualitative census of larvae and pupae requires meticulous, repeated checks on as many olive trees as possible during the study period. It took much work to follow a well-defined sampling method. In addition, it took some more work to find the larvae and pupae present in the infested olive fruit or in the soil. For this reason, all olive fruits containing larvae collected from olive trees on different dates were taken into consideration for the calculation of emergence rates, sex ratio, and parasitism.

We put olives at room temperature in the laboratory. After we sanitized them with a diluted bleach disinfectant solution and dried them with sterile paper to avoid the appearance of fungi, we put olives in a clear plastic box on a net screen large enough to allow larvae and pupae to pass. Providing favourable conditions for olive fruit fly reproduction is necessary for their development. Larvae and pupae were collected along with the olive fruits on which they were found. These were then placed in Petri dishes; the date of collection and place of harvest were noted. The boxes reserved for the larvae and pupae were covered with a piece of tulle, which did not hinder the breathing of the parasitoids inside the pupae; the emerged *Bactrocera oleae* adults and parasitoids were then identified under a binocular magnifying glass and a digital microscope. Pupae that had not yet emerged were left in Petri dishes for up to 20 days, sufficient time for the emergence of olive fruit fly pupae that had not died or diapaused. We counted the pupae every second day. After a fortnight, adult emergence is monitored daily. We assessed the rate of parasitism and the nature of the parasite by counting flies and emerging parasites. Reproduction also enabled us to determine the duration of pupal development on different dates. Based on the number of adults emerging, we can estimate pupal survival rates, as well as fly sex ratios.

Host production

We conducted rearing experiments under stable conditions of temperature (22°C ± 2°C) and relative humidity, around 55%, with a 16-hour lighting period.

Bactrocera oleae rearing was relatively straightforward and consisted of three stages. The 10 boxes were filled with a dish containing around 30 larvae and pupae. Small boxes of nutrient medium and a drinking trough were also added for future adults. Five to six days after adult emergence, olive flies started laying eggs in olive fruits, which we used as larval feeders to maintain normal conditions in the laboratory. The first larvae generally hatched 48 hours later. 8 days after their creation, the boxes were opened and placed in another, larger box with a covered bottom to facilitate the pupation of larvae, and the tulle to facilitate aeration. After ten days, we recovered the pupae.

Rearing of the parasitoids

Psyttalia concolor is a Hymenoptera of the Braconidae family. The adult is a small, tawny-coloured insect, almost 3.5 mm long, with darker pigmentation on the long antennae. The rearing experiment for *Psyttalia concolor* was conducted at the rearing laboratory temperature. The breeding room was equipped with transparent plastic boxes. The boxes used were disinfected to avoid the risk of contamination by fungi or the multiplication of undesirable insects.

At the same time, *Bactrocera oleae* was being reared to provide larvae for the parasitoids to use as hosts. For this purpose, olive fruits were collected in various regions of Biskra and incubated. Individuals emerging from these fruits constituted the first generation of laboratory rearing. After 25 days, *Bactrocera oleae* larvae were collected using the same procedure as for rearing the parasitoids.

We placed *Bactrocera oleae* larvae in the boxes containing the adult parasitoids. The pupae resulting from the pupal phase of the third instar larvae were collected using a soft brush and placed on a rearing medium until the adults' emergence. Once the adults had emerged, the parasitoids were transferred to new boxes for a new development cycle. We collected infected olive fruits containing the larvae of *Bactrocera oleae*, which were then placed in other rearing boxes for larval pupation, with muslin lids, and we placed them under the same rearing conditions as mentioned before.

Data acquisition

Our work was carried out at the laboratory, enabling us to monitor the evolution of adults, as well as that of parasites. The results of rearing carried out in the laboratory, which yielded pupae and adults, enabled us to follow the complete development cycle of *B. oleae*. To compare the use of different parasite densities on olive fruit fly populations, we used ANOVA analysis of variance at $\alpha = 0.05$ significance level. This test was performed in Excel 2019.

3. Results and discussions

We placed the larvae and pupae emerging from olive fruits in boxes for 8 days to be used in our experiments and to maintain rearing until the emergence of adults. After this period, we sequentially counted the adult olive fruit flies and the parasitoids. *Psyttalia concolor* (Braconidae: Opiinae) emerged from pupae where adults were found. This parasitoid mainly attacks the *Bactrocera oleae* species of Tephritidae present in a wide range of olive varieties. In our case, in all samples, the emerged *Psyttalia concolor* individuals were accompanied only by the *B. oleae* fly. This species may be the dominant current host of the parasitoids in Biskra (Algeria).

Adult emergence of the parasitoid Psyttalia concolor *and the olive fly* Bactrocera oleae *(*figs 1–7*).*

Figure 1. Adult female *Bactrocera oleae* laying an egg under the fruit epidermis

Figure 2. Parasitized L3 larva of *Bactrocera oleae* (left); L3 larva and prenymph of unparasitized *Bactrocera oleae* (right)

Figure 3. Olive fly pupae *Bactrocera oleae*

Figure 4. Adult emergence of *Bactrocera oleae*

Figure 5. Adult *Bactrocera oleae* – female (left), male (right)

Figure 6. Adult *Psyttalia concolor* – female (right), male (left)

Figure 7. Parasitized L3 larva of *Bactrocera oleae* and *Psyttalia concolor* adults

The olive fruit fly larvae were collected from infected olive fruits and deposited on a stretched muslin, usually for 24 hours. The larvae were transferred to a small plastic box, which was placed in a larger, aerated box for pupation. The first olive fruit fly adults (from non-parasitized larvae) emerged from the pupae after around 11 days, with the first *P. concolor* emerging after 10 to 11 days. Under controlled conditions, only 90 larvae were parasitized out of a total of 300 olive fly larvae and pupae, which is 30%. Moreover, according to our observations, a period of 10 days corresponds to the time required for the first appearance of *Bactrocera oleae* and *Psyttalia concolor* adults.

Figure 8 shows the emergence of the parasitoid and olive fly adults. The conditions applied were: temperature – 22°C ± 2°C; relative humidity – around 55%; lighting period – 16 hours.

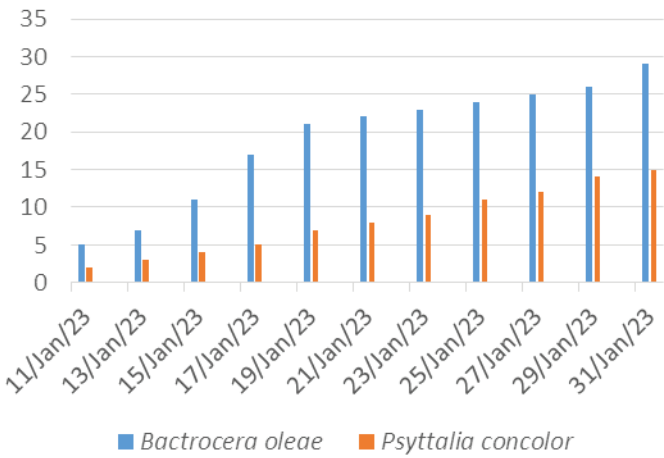

Figure 8. Adult emergence of the parasitoid *Psyttalia concolor* and of the olive fly *Bactrocera oleae*

P. concolor females prefer the L3 larval stages, pre-pupae, and pupae of *Bactrocera oleae* for oviposition. All the stages presented to the females were larvae, prepupae, and pupae, which were large and easily distinguishable to the naked eye. These stages were reached 10 days after oviposition under rearing conditions. Parasitoids were reared under the same rearing conditions as above, on *Bactrocera oleae* larvae, which were introduced into plastic boxes containing fruit infested with olive fly larvae at L3 stage. The boxes were placed in a laboratory at 22 °C, and three days later the parasitoids were removed and introduced into other boxes containing host larvae. The boxes were kept under the same rearing conditions until adult emergence – a generation of *P. concolor* developed in around 10 to 20 days. Parasitoid species were used immediately or introduced into rearing boxes until they were used for experiments on reproductive success and the biological control test.

Anova: Single factor

To test the time effect and the interaction between this factor and the variation in total adult emergence, we analysed variance (ANOVA). The results of the probability test are shown in *Table 1*.

Table 1. Analysis of variance with two classification criteria at a 5% threshold for total adult emergences

SUMMARY

Groups	**Count**	**Sum**	**Average**	**Variance**
Bactrocera oleae	11	210	19.09091	64.69091
Psyttalia concolor	11	90	8.181818	19.76364

ANOVA

Source of variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	654.5455	1	654.5455	15.50054	0.000815	4.351244
Within Groups	844.5455	20	42.22727			
Total	1499.091	21				

The analysis revealed a significant variation: P value being equal to 0.000815 is significant, the same as in the case of other values below the selected threshold for significance ($P < 0.05$); this value is less than $P < 0.001$, which implies high significance.

The biological control programme has been successful with Braconidae parasitoids, which was also introduced in several countries – where recent surveys show that the parasitoid achieves over 20% of parasitism on *B. oleae* in fruits collected in the olive grove. However, the success of this parasitoid is limited to some cases, while in others it has yet to be established or yielded only low parasitism in the target species. Recent studies have reported over 50% of parasitism of *B. oleae* when reared on artificial feed [14]. The data obtained on the biology and behaviour of the olive fly have enabled us to develop an effective control strategy.

Our bred parasitoids may explain up to 30% of parasitism. However, the first individuals were reared in laboratory on *B. oleae*. Thus, host adaptation is not a barrier for the individuals. Climatic factors play a role in determining parasitoid development, longevity, and parasitism rates.

Adaptation to these factors has also been listed for the selection of a potential biological control agent, and temperature is often considered to be the most important in the acclimatization of a reared parasitoid. A temperature range of 20–25 °C is appropriate and gives rise to a higher rate of parasitism, which corresponds to the optimal temperature for the development and survival of its host *B. oleae*. In addition to climatic conditions, the physiological state of a parasitoid can modify its host selection behaviour and thus its effectiveness as a biological control agent [15].

As far as the acclimatization of *Psyttalia concolor* in the laboratory is concerned, climatic conditions in the Biskra region are generally favourable for its multiplication. The abundance of *B. oleae* should encourage its rapid expansion. Many researchers reported that *Psyttalia concolor* mainly attacks *Bactrocera oleae*, capable of further parasitizing some non-host fruit fly species. However, the host range of *Psyttalia concolor* appears to be limited to the Tephritidae family. 24-hour-old *Psyttalia concolor* females are already able to contain an average of 18 mature eggs [16]. Supplied with food, they can have up to a hundred mature eggs in their ovaries four days after emergence [17]. Moreover, parasitoids are released 8 to 10 days after emergence, mainly in olive orchards, where fruit infestation by *B. oleae* is high.

In the years to come, the installation and multiplication of this parasitoid will need to be monitored to determine its full Tephritidae host range in Biskra and its real impact on population density. Several results are expected from this future study, including the parasitoid's dispersal capacity around release zones, altitude, temperature, and rare rainfall. It would also be interesting to observe whether the parasitoid competes with other Opiinae already present in the area.

The Braconidae endoparasite *Psyttalia concolor* has been the subject of numerous studies, given its vast distribution in the Mediterranean basin, which overlaps with the southern part of its host; it covers northern Africa.

[18] began breeding *Opius concolor* as early as 1958 and conducted several experiments in 1968, ten years later, which led him to confirm that the early releases of this parasitoid would yield spectacular results. Oviposition on *B. oleae* involves all larval stages, but the female prefers the third stage [19]. The development of pre-imaginal stages is inhibited at temperatures below 15 °C, and survival rate is reduced at low relative humidity. Older larvae are resistant to cold and can withstand temperatures of 0°C for several days. Parasitoid emergence depends on host availability, density, and age [20].

Biological treatments with *P. concolor* have reduced *B oleae* populations, but without being satisfactory [21]. For this to be successful, releases must be repeated regularly. In addition, the parasitoid attacks the third larval stage, which has already caused damage to the olives [22].

[23] emphasize the need for high humidity levels for the successful rearing of *P. concolor*, while [24] confirms the importance of the availability of unharvested olives for olive fly and parasitoid populations.

4. Conclusions

This study represents a critical first step in our knowledge of Braconidae parasitism. The low olive fruit fly densities we observed are due to parasitism by *Psyttalia concolor*. The low number of individuals obtained is likely related to the limited number used during breeding campaigns. However, with its presence already detected in larval hosts, its reproduction and involvement in the control of invasive *B. oleae* species looks promising in the coming years.

The introduction of *Psyttalia concolor* into olive groves makes it possible to effectively control *Bactrocera oleae* populations and reduce the use of chemical pesticides. This environmentally-friendly approach has many advantages, particularly in terms of sustainability and biodiversity protection. It is interesting to know to what extent *P. concolor* is having an impact on the Tephritidae family in Biskra, and it is important to monitor its spread to identify all of its host species and its impact on the density of other species. It will also be crucial to monitor parasitism rates in all regions, according to host species. Finally, it will be necessary to reinforce the phytosanitary surveillance system to minimize the risk of invasion by other pests.

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The maturity of the dates and the sum of the temperatures

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Abstract. The date palm (*Phoenix dactylifera* L.) is a mesophilic tree cultivated in dry areas. Determination of the thermal index ensuring the ripening dates of the Degletnour, Ghars, and Heloua varieties in the period of 1999–2020 in the Biskra region was performed. We collected temperature data on the Biskra region and then processed the data and calculated the thermal indices of the Biskra region and the indices of the Degletnour, Ghars, and Heloua varieties. The heat index corresponds to the sum of the average daily temperatures during the fruiting period minus the zero flowering temperature of 18 °C. Our results show that in the Biskra region the average daily temperatures increase by 18 °C and even more from April to October, lasting 120 days. In the Degletnour variety, the flowering period extends over a period of 180 days from May to October, in the Ghars variety the flowering period extends over a period of 150 days from May to September, and in the Heloua variety the flowering period extends over a period of 122 days from May to August. The thermal index of the Biskra region is 2022.89 °C. The thermal index of the varieties Degletnour is 1937.24 °C, for Ghars is 1797.58 °C, and for Heloua is 1502.23 °C.

Keywords: date palm, variety, flowering time, heat index, maturity

1. Introduction

The date palm (*Phoenix dactylifera* L.) is a mesophilic plant and one of the most important crops in dry areas. It is a perennial plant that has long been domesticated and cultivated by humans for its fruit. In fact, it is the backbone of the oasis ecosystem in the Sahara. The limiting factors for date palm cultivation are high temperatures, the almost complete absence of rain, and low humidity [1].

All climatic factors are directly related to the success or failure of date palm cultivation, production, and the quality of their fruits. Therefore, when studying the extent and suitability of a particular area for the cultivation of the date palm or any of its varieties, it is necessary to take into account as many climatic factors as possible over the longest period possible.

According to [2], temperature is one of the most important factors that influence and determine the success of commercial palm cultivation and production in a given area, as it has a negative or positive impact on the flowering time and the speed of fruit growth and reaching the final stage of maturity in addition to their direct impact on the quality of the resulting dates. We mention some temperatures of particular importance that are directly related to the vegetative and fruitful growth of the date palm such as: B. the vegetative zero point, the flowering zero point, and the dormant phase [3], [4], [5], [6], [7], [8]. The best areas for growing date palms are those where the average maximum temperature is between 35 and 38 °C and the minimum temperature is between 4 and 13 °C [9], [10].

Preliminary data on temperatures in a region is still essential to pinpoint where the different varieties are grown [11]. The cultivars showed varying abilities to withstand the temperature drop, and this is believed to be due to cultivar-specific genetic factors related to the morphological characteristics of some cultivars [2].

What is the sum of the temperature in the region? What is the heat requirement for ripening dates of different varieties? The aim of this study is to determine the temperature sum for the ripening of dates.

2. Materials and methods

Our study was conducted in the Biskra region (*Figure 1*).

The temperature data used comes from the period from 1999 to 2020 (*Table 1*). The data show that the average temperatures in January, February, and March are below the blooming zero point, which is 18 °C. However, this does not include them in the calculation of the heat index.

Table 1. Temperatures for the period of 1999–2020

Month	**Mean temperature (°C)**	**Maximum temperature (°C)**	**Minimum temperature (°C)**
January	11.65	16.60	6.57
February	12.75	17.81	7.49
March	16.68	21.65	10.85
April	20.86	25.88	14.59
May	25.28	29.97	18.64
June	30.13	35.07	23.07

Month	Mean temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)
July	33.34	38.27	26.37
August	32.34	37.04	25.76
September	27.85	32.35	22.02
October	22.51	27.26	16.97
November	16.01	20.71	11.15
December	12.36	16.74	7.67

Note: Mean temperature = (Maximum temperature + Minimum temperature)/2.

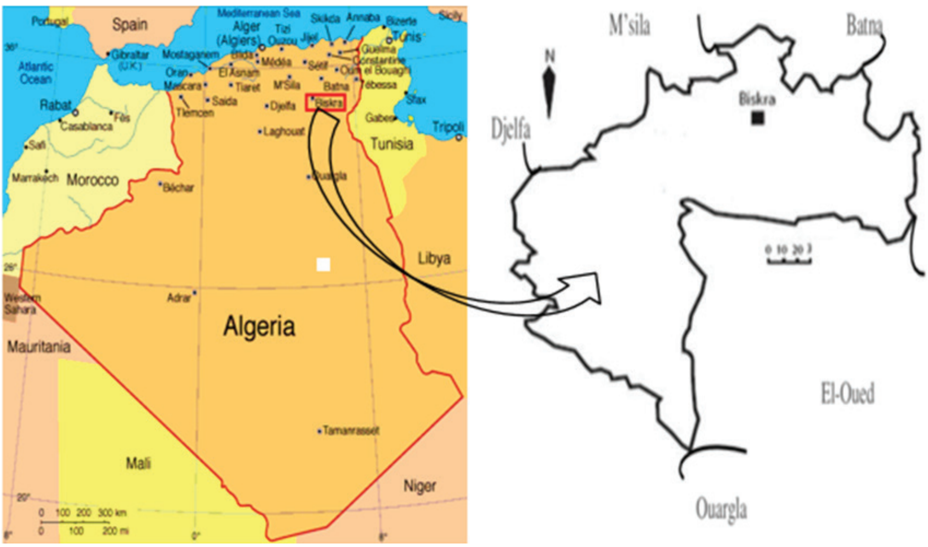

Figure 1. The map of the Biskra region where the study is carried out

Plant material

We took three palm varieties, Deglet Nour, Ghars, and Halwa, to learn the timing of flowering, pollination, and fruit setting, as well as the timing of harvest. We also collected temperature data throughout the year. The vegetation zero point is 10 °C [12], [13], [14], [15], [2]. The flowering zero point is 18 °C [16], [17], [18], [19], [2].

According to [20], the thermal index is equal to the sum of average daily temperatures greater than or equal to 18 °C, from which 18 °C is subtracted for each day during the period from flowering to ripening of dates. The ripening day is an empirical measure for calculating heat development, which is used to estimate the ripening time. The value of the number of degree days is the average between the maximum and minimum temperature of the day, from which we subtract the base temperature (zero fruiting); for date palm, zero flowering is 18 °C. The thermal index is the sum of degree days from the start of flowering to harvest.

3. Results and discussions

Our results (*Table 2* and *Figure 3*) show that in the Biskra region average daily temperatures increase by more than 18 °C for 120 days from April to October. In the Degletnour variety, the fruiting period begins with fruit setting and ends when the dates are ripe, extending over 180 days from May to October. In the Ghars variety, the fruiting period begins with fruit setting and ends with the ripening of the dates. It extends over a period of 150 days from May to September. In the Heloua variety, the fruiting period begins with fruit setting and ends with the ripening of the dates, spread over a period of 120 days from May to August. In addition, *Table 2* and *Figure 2* show that the thermal index for the Biskra region is 2022.89 °C. The thermal index of the Degletnour variety is 1937.24 °C. The heat index of the Ghars variety is 1797.58 °C, and the heat index of the Heloua variety is 1502.23 °C.

Table 2. Temperatures and thermal index

Month	**(A) Number of days**	**(B) Mean temperature of the month (°C)**	**(D) Temperature units above 18 °C**	**(E) The sum of the temperatures (°C) per month**			
				the region of Biskra	**cultivar Degletnour**	**cultivar Ghars**	**cultivar Heloua**
January	31	11.65					
February	28	12.75					
March	31	16.68					
April	30	20.86	2.86	85.65			
May	30	25.28	7.28	218.25	218.25	218.25	218.25
June	30	30.13	12.13	363.9	363.9	363.9	363.9
July	31	33.34	15.34	475.54	475.54	475.54	475.54
August	31	32.34	14.34	444.54	444.54	444.54	444.54
September	30	27.85	9.85	295.35	295.35	295.35	
October	31	22.51	4.51	139.66	139.66		
November	30	16.01					
December	31	12.36					
Sum				2022.89	1937.24	1797.58	1502.23

Notes: D = B - 18; E = A * D.

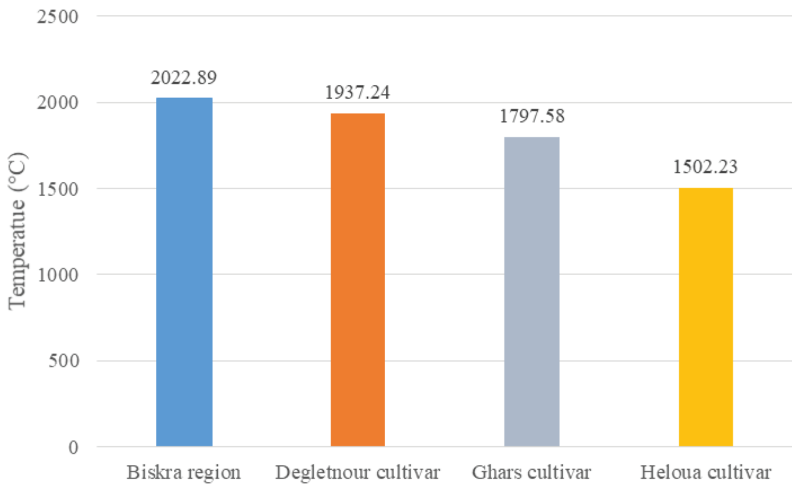

Figure 2. Presentation of heat index

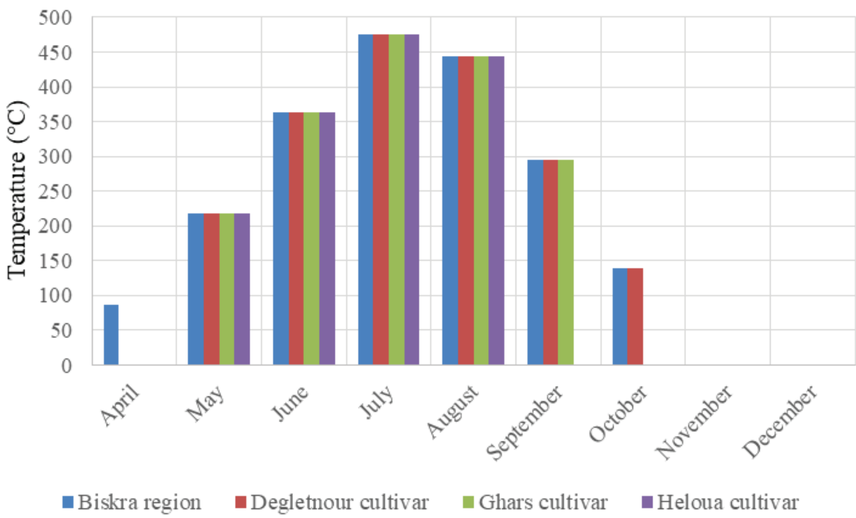

Figure 3. Presentation of monthly heat index

Based on the fruiting period and heat index of the studied varieties, the Heloua variety is early, the Ghars variety is in season, and the Degletnour variety is late. Previously, [21] conducted a study on the temperature sum in the Marrakesh region. The thermal index of the Biskra region is 2022.89 °C; this recorded index is included in the range of indices (2337–3898 °C) cited by [22], [23], and [16]. The heat index of the Degletnour variety is 1937.24 °C. The heat index of the Ghars variety is 1797.58 °C. Daily average temperatures in the Biskra region begin to rise by 18 °C and even more from April to October and last 213 days. For the Degletnour variety, the flowering period is 180 days from May to October. For the Ghars variety, the flowering period is 150 days from May to September. The Heloua variety has a flowering period of 120 days from May to August. The heat index of the Biskra region is 2022.89 °C. The heat index of the Degletnour variety is 1937.24 °C. The heat index of the Ghars variety is 1797.58 °C, and the heat index of the Heloua variety is 1502.23 °C. Based on the fruiting period and heat index of the studied varieties, the Heloua variety is early, the Ghars variety is in season, and the Degletnour variety is late. According to [20], the fruiting period of the date palm begins with fruit setting and ends with the ripening of the dates. The duration varies between 120 and 200 days depending on the variety and local climatic conditions.

In Touggourt, the length of the fruiting period varies between 150 days for early varieties, for example Ghars, and 180 days for Degletnour, with a thermal index of 1854 in Touggourt, 1620 in Bechar, 1170 in Elkantara, and 990 in Laghouat. According to [1], the duration of fruit development is 100 to 200 days depending on the variety and environmental conditions. The sum of the temperatures must reach 5,000 °C for the early varieties and 6,000 °C for the late varieties.

4. Conclusions

The Biskra region daily average temperatures start to rise by 18 °C and above from April to October, lasting 213 days. For the Degletnour cultivar, the flowering time spans 180 days from May to October. For the Ghars cultivar, the flowering time spans 150 days from May to September. For the Heloua cultivar, the flowering period spans 120 days from May to August. The thermal index of the Biskra region is 2022.89 °C. The thermal index of the Degletnour cultivar is 1937.24 °C. The heat index of the Ghars cultivar is 1797.58 °C, and the heat index of the Heloua cultivar is 1502.23 °C.

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Salinity tolerance in *Atriplex halimus* L.: Differential effects of soluble salts on seed germination and recovery

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Abstract. The soils of arid rangelands contain a variety of salts that have differential effects on seed germination. In these regions, *Atriplex halimus* (L.) (Amaranthaceae) is one of the most commonly used medicinal and fodder plants. Little is known about its germination under saline stress operated by various soluble salts. The present work was designed to determine the effect of four soluble salts (NaCl, Na_2SO_4, $CaCl_2$, and $CaCO_3$) on the germination of *A. halimus* seeds. We tested the effect of salinity on final germination percentage (FGP%) and germination tolerance index (GTI%) using five concentrations (0, 200, 300, 400, and 600 mM) of each salt (NaCl, Na_2SO_4, $CaCl_2$, and $CaCO_3$). In addition, experiments were also conducted to assess the effects of salinity on germination recovery (GRP%) from high saline conditions (600 mM). Salinity level and salt composition significantly influenced germination characteristics. *A. halimus* seeds were non-dormant, exhibited approximately 90% germination in distilled water. Both FGP and GTI gradually decreased with increasing salinity. This study showed that the seeds of *A. halimus* can germinate under 400 mM in all tested salts. The salts causing germination inhibition exhibited specificity, with an increasing trend observed in the following sequence: Na_2SO_4 > NaCl > $CaCl_2$ > $CaCO_3$. When ungerminated seeds are transferred from 600 mM to distilled water, their germination ability is recovered according to the type of salt used. *A. halimus* is a highly salt-tolerant species that can tolerate a variety of salts and can be, therefore, a promising species for improving ecological balance in saline soils.

Keywords: arid rangelands, *Atriplex halimus*, germination, tolerance, soluble salts, recovery

1. Introduction

Among the approximately 2,400 halophyte species, information on seed germination is limited to only a few hundred species, mainly concentrated in subtropical halophytes [1]. Plant species that are able to thrive in saline regions have developed a variety of adaptation strategies to cope with the challenging environmental conditions, including preserving seed viability, facultative dormancy, and prompt seed germination when hypersaline conditions are alleviated [2]. One of the most significant characteristics of halophytes is their ability to germinate despite exposure to high salinity. However, a considerable degree of heterogeneity can be discerned between halophytes in terms of their ability to recover from high salinity [3].

For the successful restoration of species, direct sowing is one of the most important steps in seed germination, and it requires an exhaustive understanding of how to create the ideal conditions for seed germination in order to maximize the success of the restoration process [4]. Many halophyte seeds can germinate when appropriate conditions for germination are met, including hypersaline conditions and other physicochemical factors [5]. The native environment of halophyte seeds is defined by the existence of saline stress, primarily caused by the prevalence of sodium chloride (NaCl), the predominant salt. The soils in the saline regions of Algeria, specifically, have been observed to accumulate high concentrations of chlorides and sulphates, with NaCl being the most prevalent salt in these soil compositions. The predominant cationic components in these soils consist of Na^{+}, Ca^{2+}, K^{+}, and Mg^{2+}, with SO_4^{2-} being identified as the secondary major anionic element after Cl- [6, 7]. The salinity present in the environment negatively affects most glycophytes. However, halophyte seeds often exhibit complete recovery after the removal of saline stress, suggesting the presence of an osmotic response [8].

Atriplex halimus L. (Amaranthaceae), commonly known as Mediterranean saltbush in English and *Gtaf* in Arabic (Algeria), is a perennial shrub that thrives in saline conditions. It grows in semi-arid and arid environments across Eurasia, spanning from the Atlantic coasts through the countries of the Mediterranean basin and into the Middle East [9]. *A. halimus*'s capacity to thrive in challenging environmental conditions has led to its traditional utilization as a source of grazing fodder for livestock in these regions [10]. It grows in regions characterized by low annual rainfall and high potential evapotranspiration, typically at limited altitudes, below approximately 1,200 m above sea level [11]. The primary mode of propagation for *A. halimus* is through seeds. *A. halimus* generally forms part of the halophilic communities on saline soils. Le Houérou [11] also classified *A. halimus* as a "euhalophyte", capable of tolerating soil salinity levels equivalent to saturated paste EC values ranging from 25 to 30 dS.m-1. *A. halimus* belongs to a group of species demonstrating moderate cold tolerance, enduring temperatures between -10 and -12 °C.

Since the 1960s, *A. halimus* has been intentionally grown in the Mediterranean arid zone to serve as standing feed for browsing, as well as to provide silage for various animals, including small ruminants like sheep and goats, as well as larger livestock such as cattle and camels [12, 13]. The cultivation of *A. halimus* fosters the recycling of nutrients, contributes to phytoremediation, reduces ground-level wind speed, and plays a role in decreasing runoff and erosion [14]. Indigenous herbal practitioners in Arabic regions used the leaves of *A. halimus* to treat heart diseases and rheumatism. They prepare an extract by boiling the leaves, which is then added to bath water for therapeutic purposes [15]. The antidiabetic effect has been further developed in a product called "Glucolevel", which combines leaf extracts of *A. halimus*, Juglans regia L., *Olea europaea* L., and *Urtica dioica* L. [16]. Extracts derived from the aerial parts of *A. halimus* exhibited antibacterial activity against a range of Gram$^+$ and Gram pathogenic bacteria [17]. Endophytic fungi isolated from *A. halimus* demonstrated antimicrobial effects against specific species [18].

In most experiments assessing the impact of salt stress on seed germinability characteristics of *A. halimus*, sodium chloride (NaCl) is used alone to assess the impact of salt stress [19, 20, 21, 22]. Few studies explore the effects of other prevalent soluble salts. The present study describes the effect of different salts on seed germination and recovery of *A. halimus* after exposure to high salinity level. We attempt to establish the effects of the most abundant soluble salts in Algerian arid rangelands *viz*. NaCl, Na_2SO_4, $CaCl_2$, and $CaCO_3$ on the germination of this important plant species. The findings of this research will significantly contribute to enhancing our comprehension of the germination requisites of this species, thereby aiding in the restoration of degraded rangelands and the establishment of new territories. These efforts are crucial to provide valuable food for humans and animals, offering both medicinal and nutritional benefits.

2. Materials and Methods

Seed harvesting

Mature seeds of *A. halimus* were collected randomly in 2022 from the arid rangeland of T'Kout, located in Batna, southeastern Algeria. At least 10 plants were sampled for seed collection in this area (Latitude 35°09' N; Longitude 6°20' E; 1049 m a.s.l.). The seeds were manually separated from the fruits (pericarp). Typically, these seeds exhibit a brown to dark brown colour, and their shape ranges from reniform to sub-orbicular, with an entire or toothed appearance. The weight of 100 seeds of *A. halimus* is 2.89 g. Following collection, the seeds were stored in opaque paper bags at room temperature, maintaining a humidity level between 30 and 50%, until they were used three months later [23].

Experimental design and application of salt stress

We conducted germination tests using a 90-mm Petri dish containing a disk of Whatman No. 1 filter paper moistened with distilled water for a control as well as various saline solutions containing various concentrations (200, 300, 400, and 600 mM) of the following soluble salts: NaCl, Na_2SO_4, $CaCl_2$, and $CaCO_3$. For each test (salt/concentration), four replicate Petri dishes, each with 100 seeds, were wrapped in aluminium foil (continuous dark) and incubated at 25 °C [6, 7]. The emergence of radicles was considered as the criterion for germination. The Petri dishes remained sealed for 15 days after the experiment had concluded. Maintaining appropriate humidity levels throughout the experiment was crucial for seed viability. The germination test was conducted using a complete randomized design.

Germination traits

Based on the results of the quantitative evaluation of seed germination behaviour, the following formulas have been used to calculate both the final germination percentage (FGP) [24] and the germination tolerance index (GTI) [25]:

$$FGP\ (\%) = \frac{Number\ of\ germinated\ seeds}{Total\ number\ of\ seeds} \times 100$$

$$GTI\ (\%) = \frac{FGP\ under\ stress\ condition}{FGP\ under\ non - stress\ condition} \times 100$$

After 15 days of every salt exposure, seeds that failed to germinate at 600 mM under different types of salt were washed with distilled water and then placed in new Petri dishes with new filter paper moistened with distilled water and were then monitored for another 15 days under the same conditions for their germination recovery aptitude. The germination recovery percentage (GRP) was calculated for each treatment as follows:

$$GRP\ (\%) = \frac{(A - B)}{(C - B)} \times 100,$$

where A is the number of seeds germinated over the entire experiment, B is the number of seeds germinated in saline solution, and C is the total number of seeds used for processing [25].

Statistical analysis

Statistical analysis was carried out using two-way analysis of variance (ANOVA) to test the effects of salt type, concentration, and their interaction on germination characteristics. Multiple comparisons of means were carried out using Tukey's test ($P < 0.05$). Mean values were presented in terms of mean ± standard error (mean ± SE). Pearson's correlation coefficient was also considered to establish the relationships between the values of salt concentrations and germination parameters ($P < 0.05$). All statistical analyses were performed using SAS software Version 9.0 (Statistical Analysis System) (2002).

3. Results and discussion

Effects of salinity on final germination

Salinity and drought are two of the most significant abiotic challenges impeding seed germination and the establishment of plants in Mediterranean regions [26]. The use of resilient plant species could be considered a possible strategy for cultivating saline soils, which are unsuitable for most traditional agricultural crops due to their elevated salinity levels [27].

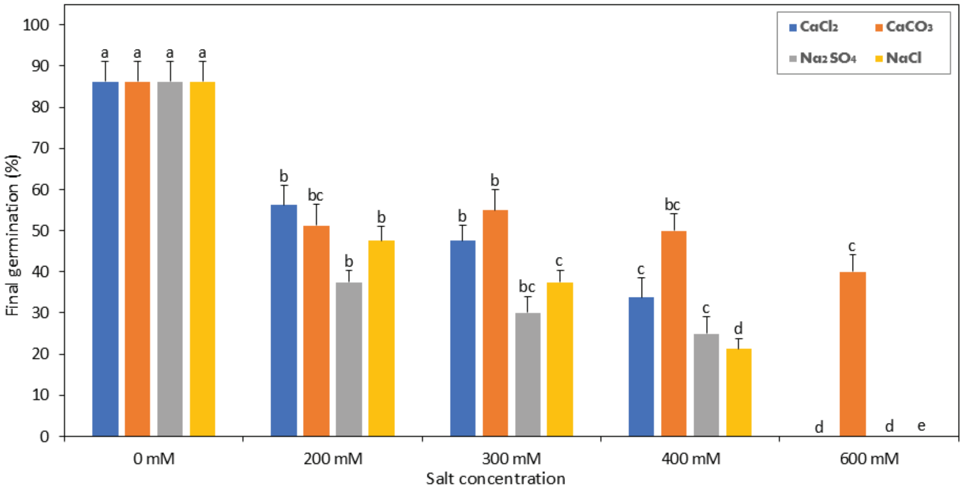
Table 1. Results of two-way analysis of variance (F values) testing the effects of salts (S), concentrations (C), and their interaction (S × C) on the germination characteristics of *Atriplex halimus* seeds

Independent variables	Salts (S)	Concentration (C)	(S × C)
FGP	75.57*	549.78*	14.32*
GTI	82.30*	599.80*	15.68*

Notes: FGP – Final Germination Percentage; GTI – Germination Tolerance Index; * $P < 0.0001$.

The results from the two-way ANOVA analysis revealed significant adverse effects on the germination percentages of *A. halimus* seeds attributed to both salt type ($F = 75.57$, $P < 0.0001$) and salt concentration ($F = 549.78$, $P < 0.0001$), as well as their interactions ($F = 14.32$, $P < 0.0001$) (*Table 1*).

In the presence of all types of salts at 600 mM, germination is completely inhibited. However, only seeds treated with $CaCO_3$ germinated, by recording 40% FGP (*Figure 1*). According to *Figure 1*, *A. halimus* seeds germinate better under relatively moderate salinity conditions of 200–300 mM. A significant reduction in germination percentages was observed beyond these levels, regardless of the type of salt.



Notes: Bars represent mean ± SE (n = 4). Different letters indicate significant difference between treatments (Tukey test, $P < 0.05$).

Figure 1. Final germination percentages (FGP) of *Atriplex halimus* seeds treated with different soluble salts

A notable decrease in Final Germination Percentage (FGP) was evident for all four salts compared to the control (*Figure 1*). The relationship between FGP and soluble salt concentrations displayed strong statistical regressions, exhibiting coefficients of determination (R^2) ranging from 0.73 to 0.96 (*Figure 2*).

It is important to emphasize that in comparison to the other types of salt solutions tested, the germination capacity of *A. halimus* seeds was more adversely affected by solutions of NaCl and Na_2SO_4. According to *Figure 2*, the FGP had highly significant and negative linear relationships with concentrations in all salt types, indicating that salt treatments negatively affected *A. halimus* seed germination. According to our results, *A. halimus* seed germination was best obtained in distilled water (control) and in all concentrations of $CaCO_3$ when a salt solution was applied; however, with an increasing degree of other salt solutions, there was a gradual decrease in germination potential depending on the salt type as well as the concentration of salts. At 400 mM, sodium chloride and sodium sulphate were more detrimental than calcium chloride (*figures 1–2*).

Based on our previous research on the glycophyte *Phaseolus vulgaris*, we found that under various salts, germination would decrease in the order of NaCl > KCl > $CaCO_3$ > Na_2SO_4 > $CaCl_2$ [6]. The study conducted by Bernstein [28] highlighted a significant correlation between plant response and soil osmotic potential, particularly in the presence of elevated concentrations of Ca^{2+} and Na^+ in saline soils. Conversely, non-saline sodic soils characterized by high Na^+ levels and minimal Ca^{2+} and Mg^{2+} concentrations can lead to distinct nutritional deficiencies not typically observed in saline soils. The short-term adaptations to changes in osmotic pressure due to salination are regulated by the concentrations of K^+ and organic acids within the plant cells. As osmotic adjustment progresses over the subsequent days, additional cations and anions might start replacing the organic salts of potassium, influencing the overall process of osmotic adjustment [29]. Several forage species classified as halophytes and belonging to families such as Poaceae, Fabaceae, and Amaranthaceae have been observed to undergo similar effects when exposed to various soluble salts [30].

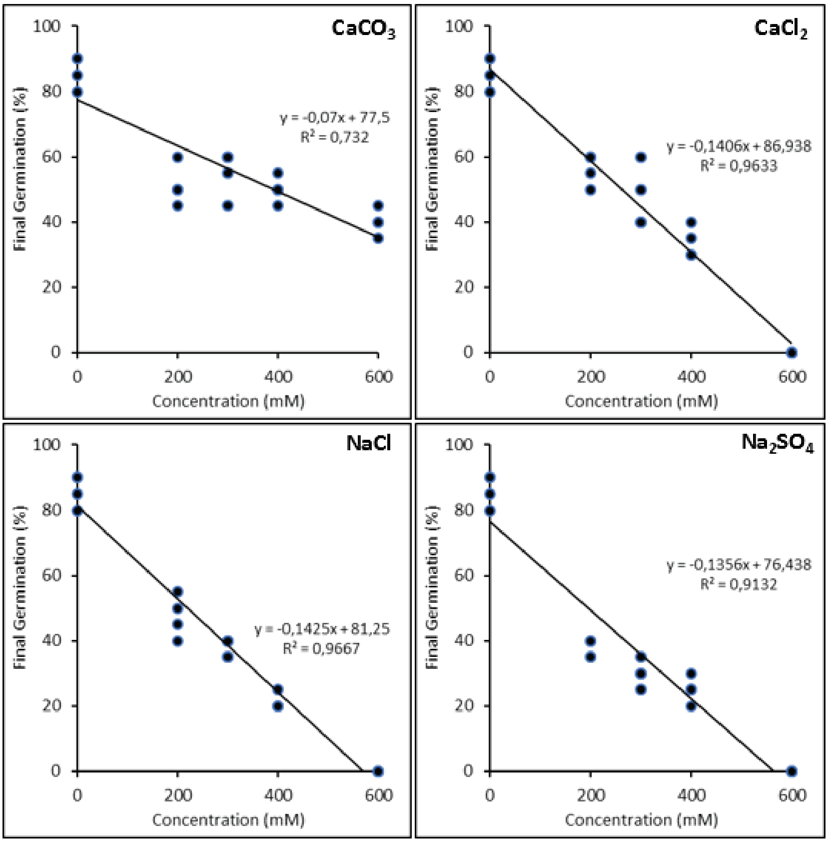


Figure 2. Regression plots of final germination percentages of *Atriplex halimus* seeds with different soluble salts

Debez et al. [31] showed that the seed germination of a coastal population of *A. halimus* exhibited greater salt tolerance compared to a population from a non-saline site. Complete inhibition of germination occurred at 700 mM NaCl for the coastal population and at 350 mM NaCl for the non-saline site, signifying very high tolerance levels in both cases. According to [32], the application of NaCl and Na_2SO_4 at a concentration of 200 mM to the seeds of the halophyte *Portulca oleracea* led to a significant reduction in germination rates. This reduction in germination could potentially be attributed to prolonged germination times, likely caused by the challenge in seed hydration due to the high osmotic potential induced by these salts. Indeed, the extended duration for seeds to establish mechanisms facilitating internal osmotic pressure adjustment could account for the prolonged germination process. This delay might occur as the seed initiates adaptations to cope with the altered osmotic conditions induced by salt stress, contributing to the prolonged germination period [33].

McGaughey et al. [34] demonstrated that alterations in salinity levels could affect seed aquaporin function, consequently influencing seed germination. In saline environments, the prompt germination of Mediterranean halophyte fodder species plays a crucial role in facilitating successful plant establishment. Consequently, these plants exhibit rapid propagation and the development of deep root systems, enabling them to absorb moisture from deeper soil layers during periods of drought. This adaptive ability assists in their resilience during dry seasons by accessing moisture from deeper areas in the soil [35].

Effects of salinity on germination tolerance index

Salinity in soils is influenced by a wide range of ions such as Cl^-, SO_4^{2-}, HCO_3^-, Na^+, Ca^{2+}, Mg^{2+}, and, more rarely, NO_3^- or K^+. It is common in nature to find salts of these ions at highly variable concentrations and proportions. Although these ions may be indigenous to an area, most often they are brought into it through irrigation water or water flowing from adjacent areas [36]. In arid regions, the natural drainage systems frequently exhibit inadequate functionality, leading to the accumulation of salts within inland basins instead of their discharge to the sea [1].

Table 2. The Germination Tolerance Index (%) of *Atriplex halimus* seeds treated with different soluble salts

Concentrations	**$CaCO_3$**	**$CaCl_2$**	**NaCl**	**Na_2SO_4**
0 mM	100^a	100^a	100^a	100^a
200 mM	59.5^b	65.1^b	55.2^b	43.5^b
300 mM	63.8^b	55.7^b	43.5^c	34.9^c
400 mM	57.9^b	39.4^c	24.6^d	29.1^c
600 mM	46.4^c	0.00^d	0.00^e	0.00^d

Note: Different letters indicate significant difference between treatments (Tukey test, $P < 0.05$).

Results of a two-way ANOVA indicated a significant effect of salts (S) ($F = 82.3$, $P < 0.0001$) and concentrations (C) ($F = 599.8$, $P < 0.0001$) and their interaction ($S \times C$) ($F=15.68$, $P < 0.0001$) on the GTI (*Table 1*). The inhibitory effect of salt stress on the Germination Tolerance Index (GTI) was more pronounced for NaCl and Na_2SO_4 at a concentration of 400 mM (*Table 2*).

In sodic soils, the primary cations predominantly present are sodium alongside carbonate, and bicarbonate serves as the most prevalent complementary anion. Therefore, soils characterized by excessive levels of soluble salts are categorized as saline soils, those exhibiting high levels of exchangeable sodium are termed sodic soils, and soils that possess elevated concentrations of both salts and exchangeable sodium are identified as saline-sodic soils [37]. The salts causing germination inhibition exhibited specificity, with a decreasing trend observed in the following sequence: $CaCO_3 < CaCl_2 < NaCl < Na_2SO_4$ (*Table 2*). Nedjimi and Zemmiri [38] found that $MgCl_2$ and Na_2SO_4 were generally the most toxic salts regarding *Artemisia herba-alba* seed germination, followed by NaCl and $CaCl_2$.

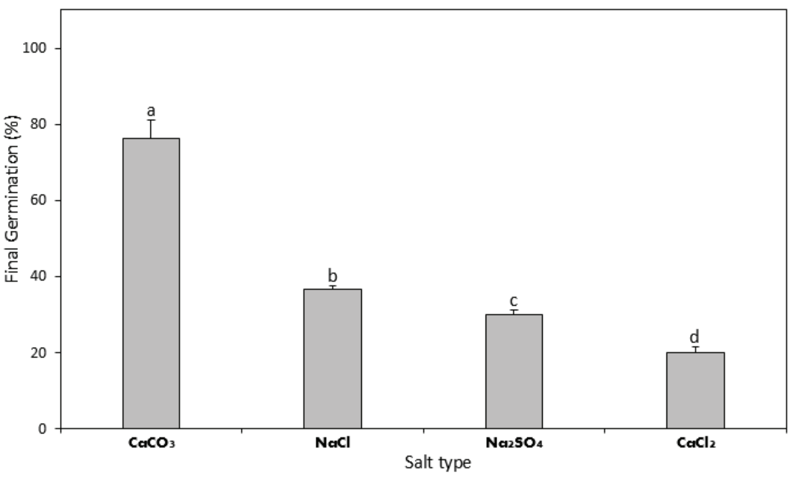
According to [39], saline soils primarily contain NaCl and Na_2SO_4 as the major solutes. Sodium chloride exhibits high solubility at 264 g L^{-1}, posing a significant threat to plant growth. Even soils with just 0.1% NaCl are considered highly unsuitable for supporting plant growth. Saline soils can contain concentrations of 2–5% NaCl, necessitating modifications through leaching to decrease its concentration and create a more favourable environment for plant growth. While sodium chloride is rarely directly observed in soils, it forms calcium sulphate and carbonate, precipitating due to reactions with sodium sulphate and carbonate, unless water salinity is exceptionally high (ranging from 500 to 400 mg) within the soil. Calcium chloride ($CaCl_2$), though toxic to plants, exhibits lower toxicity compared to sodium chloride. Sodium sulphate is a prominent component found in saline soils, saline groundwater, and saline lakes. Its solubility increases with higher temperatures.

The less toxic salts regarding the germination of *A. halimus* seeds were calcium chloride ($CaCl_2$) and calcium carbonate ($CaCO_3$) (*Table 2*). This could be attributed to the beneficial impact of calcium on maintaining membrane integrity, regulating ion selectivity, and reducing ion leakage from the membrane [40]. [41] demonstrated that the application of organic amendments would likely elevate the quantity of calcium (Ca^{2+}) derived from calcium carbonate ($CaCO_3$). This increase is attributed to the formation of organic acids during the application of organic amendments. During saline conditions, the starch hydrolysis and mobilization of reserves from the endosperm to the embryo were inhibited primarily by excessive levels of soluble salts in the endosperm. It is possible to observe a correlation between germination tolerance and species ecology [42].

Nevertheless, despite the detrimental impacts of soluble salts, this study demonstrates that the seeds of *A. halimus* have the capability to germinate even under high concentrations of 400 mM for all tested salts (*Table 2*). This level of salinity exceeds the salinity tolerance level of the majority of cultivated vegetable species, as well as of several halophytes [43, 44]. According to [45] and the recent results of [46], seeds from various steppe plant species exhibit the capacity to maintain their viability for extended durations even when subjected to severe conditions, particularly salinity and drought. They retain this ability to propagate when ecological conditions become favourable again. Seeds from plants common to arid climates typically mature during the autumn, and their germination begins shortly after the initial precipitation of the spring season. These seeds are commonly situated in the upper layers of the soil and germinate when elevated salt concentrations are leached from the soil by rainwater.

Effects of salinity on seed germination recovery

Results of a one-way ANOVA indicated a significant effect of salts ($P < 0.0001$) on the GRP. The test of germination recovery in the presence of salt consists of transferring seeds that have not germinated on a medium containing salt to a medium devoid of salt in order to detect the nature of the effect of salt if it is toxic or osmotic for the same period of time as the germination test. When seeds that have not germinated at high concentration (600 mM) are transferred to distilled water, the process of germinating the seeds is enhanced to 76.3%, 36.7%, 30%, and 20%, using $CaCO_3$, NaCl, Na_2SO_4, and $CaCl_2$ respectively (*Figure 3*). Based on these results, it is possible to classify *A. halimus* as a highly salt-tolerant species. Seeds of *A. halimus* did not recover completely and showed average recovery response (< 30% FGP) when subjected to high salinity of NaCl, Na_2SO_4, and $CaCl_2$.



Notes: Bars represent mean ± SE (n = 4). Different letters indicate significant difference between treatments (Tukey test, $P < 0.05$).

Figure 3. Germination recovery of ungerminated salt-treated seeds of *Atriplex halimus* at 600 mM

Exposure to high temperatures combined with salinity can lead to a decline in seed viability, consequently resulting in poor recovery response [47]. Certainly, the capability to recover following salt exposure varies among different species. Seeds from various species possess the ability to sustain their viability even under hyper-saline conditions and subsequently initiate germination once the salinity stress reduces. This phenomenon is notably observed in halophytes [48, 49].

Indeed, while there are differences in salt sensitivity among various species during germination, most halophytes maintain seed viability even when exposed to high salt concentrations during their dormancy period [48]. In this study, after ungerminated seeds were transferred to distilled water, *A. halimus* seeds exhibited rapid recovery under conditions involving $CaCO_3$, $CaCl_2$, Na_2SO_4, and NaCl. A proteomic analysis uncovered that in the presence of salt, the extensive conversion of reserve proteins into 20 amino acids, which could be further transformed into other amino acids, as well as the conversion of fatty acids into carbohydrates, was decelerated. However, under favourable recovery conditions, this conversion process was promptly reinitiated [50].

The distribution and prevalence of halophytes in saline environments are influenced by the variances in germination responses. Halophyte seeds maintain their viability even after prolonged exposure to salt stress, remaining dormant until favourable conditions for germination arise. However, excessive salinity levels can entirely prevent seed germination, surpassing the tolerance limits of the species [51]. [52] showed that *Salicornia europaea* and *Suaeda calceoformis* seeds recovered significantly faster than controls from two-year saline pre-treatments. This observation confirms the osmotic influence of salt on the germination process of halophytes. Such behaviour represents a typical life cycle strategy adopted by halophytes residing in desert regions to enhance their chances of survival. This strategy allows populations to sustain stability and uphold ecological balance over time [47].

4. Conclusions

The current study aimed to explore the impact of soluble salts on the germination process of *A. halimus*, a plant renowned for its forage, nutritional, and medicinal properties, particularly in the arid and semi-arid rangelands of Algeria. Our findings revealed that *A. halimus* seeds exhibited germination capability even under high concentrations (≤ 400 mM) of soluble salts despite the overall negative influence of salinity. Notably, salts like NaCl and Na_2SO4 displayed a more pronounced inhibitory effect on *A. halimus* seed germination compared to $CaCO_3$ and $CaCl_2$. This varying behaviour observed in *A. halimus* seeds in response to different salt types is attributed to the generation of distinct osmotic potentials by the same concentration of salt, with the osmotic effect playing a more significant role in influencing germination in this scenario. *A. halimus* emerges as a highly promising crop for enhancing land productivity in arid and semi-arid regions. The purpose of this practice is not just to address the needs of the food industry but also to contribute to sustainable land management practices in challenging environmental conditions.

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Biogas production as a catalyst for energy autonomy and sustainable agriculture: A case study projection at Toro Impex Ltd

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Abstract. This research explores the establishment of a biogas plant at Toro Impex Ltd, converting pig manure and slaughterhouse residues into biogas for energy self-sufficiency and environmental benefits. It highlights the production of both electrical and thermal energy, with electricity contributing to the local grid and heat serving nearby industries. The study finds significant reductions in greenhouse gas emissions and odour pollution, alongside high-quality organic digestate for soil improvement. It also addresses socioeconomic impacts like job creation and local energy autonomy, offering a model for integrating waste management, renewable energy, and sustainable agriculture in rural contexts.

Keywords: energy self-sufficiency, agricultural waste to energy, environmental sustainability, circular economy

1. Introduction

In recent years, the agricultural and food processing industries have faced significant challenges related to energy consumption and waste management [1], [2]. This is particularly evident in rural industrial entities, which often lack a clear path for efficient energy use and sustainable waste management [3]. The agro-food industry, comprising pig farms and slaughterhouses, stands out as a sector with high energy demands and considerable waste production, necessitating innovative solutions to address these issues [4]. Pig farms and slaughterhouses are prime examples of this, as they require substantial amounts of thermal energy and power for various operations [5]. However, these industries often operate in remote areas where access to reliable and sustainable energy sources is limited. The lack of a clear path for energy and waste management not only poses operational challenges but also leads to increased environmental impacts [6] [7].

The processes involved in rearing pigs, slaughtering, and processing meat demand significant thermal energy and electricity [8]. For instance, maintaining optimal conditions in pig housing, including heating and ventilation, requires continuous energy input. Similarly, slaughterhouses utilize large amounts of energy for processes such as scalding, dehairing, evisceration, and cooling. Therefore, these facilities highlight the need for efficient energy management strategies to ensure operational sustainability and cost-effectiveness [9].

The energy dependency of agro-food industries on fossil-based energy resources such as natural gas and other conventional sources has been a significant concern [10]. This dependency has exposed these industries to various risks, particularly in the light of recent energy crises and price volatility [11]. The energy crisis in recent years has exacerbated these issues, highlighting the vulnerability of businesses that rely heavily on non-renewable energy sources [12]. The fluctuating availability and cost of fossil fuels have underscored the need for alternative, renewable energy sources that can provide greater stability and sustainability [13].

Renewable energy solutions, particularly those based on biogas, offer a viable pathway to reducing energy dependency and mitigating the risks associated with energy crises [14], [15]. By harnessing the energy potential of organic waste, pig farms and slaughterhouses can achieve greater energy independence and stability [16], [17]. This shift towards renewable energy not only addresses operational challenges but also aligns with broader environmental goals, including the reduction of GHG emissions [18].

A major challenge confronting the contemporary agro-food industry involves addressing climate change, necessitating substantial mitigation efforts targeting the reduction of emissions of greenhouse gases (GHGs) [19], [20]. The adoption of biogas systems in pig farms and slaughterhouses can significantly contribute to reducing GHG emissions. Biogas production through anaerobic digestion captures methane, a potent GHG, that would otherwise be released into the atmosphere from untreated waste. The use of biogas as a renewable energy source further displaces fossil fuel consumption, leading to additional reductions in $CO2$ emissions [21].

One promising solution to address the energy and waste management challenges in pig farms is the production of biogas [22]. Biogas, primarily composed of methane, can be produced through the anaerobic digestion of organic waste, such as pig slurry [23]. This process not only reduces waste but also generates renewable energy that can be used to meet the energy demands of pig farms and slaughterhouses [24].

The potential of biogas production from pig farms to achieve energy self-sufficiency warrants detailed analysis [25]. By assessing the amount of biogas that can be produced from pig slurry, fluid by-products from slaughterhouses, and other organic waste, it is possible to determine the extent to which this renewable energy source can meet the thermal and electrical energy needs of these facilities [16]. This analysis involves evaluating factors such as the quantity and composition of waste, the efficiency of anaerobic digestion processes, and the energy requirements of the farm and processing operations [26].

There are several case studies and examples of medium- and large-sized dairy farms that have real potentials [16] but have also successfully implemented biogas systems to achieve energy self-sufficiency [27]. These examples can provide valuable insights and lessons for pig farms and slaughterhouses looking to adopt similar solutions. For instance, some dairy farms have integrated biogas production with their energy systems, using the generated biogas to power generators and produce electricity, as well as to provide thermal energy for heating purposes. These solutions not only enhance energy self-sufficiency but also contribute to reducing greenhouse gas (GHG) emissions [28].

Reduced reliance on fossil fuels leads to lower energy costs and enhanced energy security. Additionally, the production and use of biogas can create new revenue streams for pig farms and slaughterhouses, further incentivizing the adoption of this technology [29]. The combination of environmental and economic benefits makes biogas a compelling solution for sustainable energy and waste management in the agro-food industry [30], [31], [32], [33].

Therefore, by evaluating the biogas potential of pig farms and analysing successful case studies from other sectors, it is possible to develop effective strategies for renewable energy adoption. The transition to biogas systems not only addresses immediate operational challenges but also aligns with broader goals of reducing GHG emissions and enhancing energy security. As the agro-food industry navigates the complexities of energy and waste management, biogas offers a viable and sustainable solution that can transform the energy landscape of rural industrial entities.

The primary objective of this paper is to explore and demonstrate the feasibility of establishing energy self-sufficiency within a rural agro-food industrial entity, specifically focusing on a pig farm and its associated meat-processing facilities. The study aims to assess how the utilization of pig manure as a feedstock for biogas production can meet the energy needs of a multifaceted agro-industrial operation. This exploration extends to the potential benefits of biogas production in terms of environmental impact, economic sustainability, and social contributions within the local community.

More specifically, the objectives of this research include:

1. Evaluation of pig manure if it can produce sufficient biogas to supply the necessary electrical and thermal energy required for the entire operation of the

farm, slaughterhouse, and other associated facilities, thus achieving complete energy independence.

2. Assessment of whether biogas production can mitigate odour pollution and reduce greenhouse gas emissions, thereby decreasing the environmental footprint of the pig farming operation.

3. Assessing the feasibility of selling surplus electricity generated from biogas back to the grid and providing excess thermal energy to neighbouring industrial sites with high heat demand, thus enhancing economic returns and fostering regional industrial synergy.

4. Examining the quality of the digestate-produced post-fermentation in the biogas plant, focusing on its potential as a high-quality organic fertilizer that can improve soil health and significantly reduce the reliance on chemical fertilizers.

5. Exploring how the establishment of a biogas plant could create new job opportunities, contribute to local employment, and support the creation of a local energy community that promotes energy autonomy, reduces dependency on energy imports, and stabilizes the local economy.

The following hypotheses guide this research:

1. Pig manure and slaughterhouse residuals, as an input material, can generate sufficient electrical and thermal energy through biogas production to support the diverse operations of the enterprise, thereby achieving energy self-sufficiency.

2. The biogas plant will significantly reduce odour pollution and prevent substantial GHG emissions, thus avoiding major environmental impacts and contributing positively to the local ecosystem.

3. The electricity generated in excess of the farm's own consumption will be sold to the grid, while the thermal energy will be used to meet the demands of neighbouring industrial sites, which have also high heat requirements, creating an additional revenue stream and promoting local industrial cooperation.

4. The post-fermentation digestate will be a high-quality matured organic material, providing an excellent nutrient source for crops when applied to fields, positively impacting soil quality compared to raw manure, radically reducing the use of chemical fertilizers.

5. The biogas plant will create new job opportunities, and it creates a local energy community, reducing reliance on imported energy, fostering energy autonomy, and resulting in a more stable energy supply for the local economy.

These hypotheses will be tested through a combination of qualitative and quantitative methods, based on case study, energy production simulations, environmental impact assessments, and economic feasibility analyses. The outcomes of this research are expected to provide valuable insights into the potential of biogas technology as a sustainable energy solution for rural agro-industrial operations, particularly in regions facing similar challenges and opportunities.

2. Materials and methods

In the present research, we approached the topic from energetic, environmental, economic, and social aspects, analysing with quantitative and qualitative methods the impact of a biogas plant on a specific company in the agro-food industry, using a real framework of a Toro Impex Ltd site in Romania, as it follows:

1. In the first step, the amount of input materials (m^3) was determined based on the number of livestock in daily, monthly, and annual breakdowns. Slurry production comes from three sources: a.) liquid manure from pig farm, b.) liquid manure from cattle breeding, and c.) wastewater and fluid by-products from slaughterhouse activities.

a.) The pig manure volumes were calculated based on the following formula (1) in a daily breakdown, and considering breeding cycles, it can also estimate weekly, monthly, or annual yield:

$$HHs = A * HT^n/1000, \tag{1}$$

where: HH_s represents the slurry yield in the case of pigs, A represents the livestock (3,500 in one breeding cycle), and HT^n represents the daily slurry production expressed in kilograms. The daily slurry production of the pigs was calculated weighted by their body weight; as a result, we can present a daily slurry production dynamic. Furthermore, the quantitative data of the daily manure production are expressed in tons in order to make the quantitative data easier to read and visualize.

b.) The second formula (2) was used to determine the quantitative yield of liquid manure from cattle breeding, broken down daily, and then we can also estimate weekly, monthly, or annual yield:

$$HHsz = A * HT^n/1000, \tag{2}$$

where: HH stands for liquid manure yield, calculating with an average livestock of 60 animals, and HT^n means the daily liquid manure production expressed in kilograms. With the previous approach, the manure production volumes were calculated with the cattle body weight, expressed in tons, in order to make the quantitative data easier to read and visualize.

c.) The quantitative determination of wastewater and other fluid by-products from slaughterhouse activities (m^3/day) are based on the plant's processing capacity depending on the number and average weight of the animals processed per day (t/day); see formula 3:

$$Fsk = S * \text{á}.t./1000, \tag{3}$$

where: F_{sk} means the volume of processed pigs (t/day), and S means the number of pigs (as an average 200 pigs/day are processed with an average weight of 98 kg, expressed in ton).

The processing of cattle was expressed with the same approach, with formula (4):

$$Fszk = Sz * á.t./1000, \tag{4}$$

where: F_{szk} means the processed cattle capacity (t/day), Sz means the number of cattle (50 every day of the year except for the days off), and the average weight of the animals is 300 kg, expressed in tons.

The following formula is used to determine the daily wastewater production of the slaughterhouse (5):

$$Vsz = (Fsk * 2) + (Fszk * 5), \tag{5}$$

where: V_{sz} represents the daily wastewater production of the slaughterhouse, F_{sk} means processed pig capacity, and F_{szk} means processed cattle capacity. Based on the study done by Ungureanu [34] at the company, the former is multiplied by a value of 2 while the latter by a value of 5. The sum of the two above-mentioned types of animal processing gives the total amount of daily wastewater production.

The following formula (6) is used to determine the amount of biogas that can potentially be produced from the daily amount of wastewater (m^3):

$$SZb = Vsz * 0.2, \tag{6}$$

where: S*Zb* represents the amount of biogas that can be produced from wastewater, multiplying the Vsz value by a value of 0.2; according to [34], the amount of biogas expressed in m^3 can be determined.

The following formula (7) is used to determine the estimated daily amount of biogas (m^3) produced by the biogas plant:

$$BTn = [(HHs + HHsz) * 400] + SZb, \tag{7}$$

where: BT_n represents the daily biogas production expressed in cubic meters. The sum of HH_s and HH_{sz} is multiplied by a value of 400. According to Pauda [35], 0.4 m^3 of biogas can be produced from 1 kg of slurry under suitable fermentation conditions. Since the amount of slurry is expressed in tons, we use the value of 400. After that, the amount of biogas produced from wastewater is added to the amount of biogas produced from slurry.

2. The production of a.) electricity and b.) thermal energy of the biogas plant was determined.

a.) The study of Akbulut (2012) serves as the basis for determining the production of electricity, according to which 2.14 kWh can be produced from 1 m^3 of biogas. The following formula (8) can be used to calculate the amount of electricity production expressed in MWh in a daily breakdown, which can later be calculated in weekly, monthly, and yearly breakdowns:

$$VeMWh = Bg * 2.14/1000, \tag{8}$$

where: V_{eMWh} expresses the quantity of electricity in MWh, B_g denotes the quantity of biogas (m^3); dividing by 1,000 is necessary to convert the 2.14 kWh value into MWh.

MWh is an internationally recognized unit of measurement for electricity, but in some countries, such as in Hungary, practice shows that MJ and GJ are also commonly used. Therefore, the amount of electricity yield was also calculated in these forms based on [36]. The formula for converting to MJ is (9):

$$VeMJ = Bg * 22, \tag{9}$$

where: V_{eMJ} expresses the amount of electricity in MJ, and B_g indicates the amount of biogas (m^3), which must be multiplied by the value of 22, as described in the study of [36]. To express in GJ, the value of MJ is divided by 1,000; in the formula, V_{eGJ} expresses the amount of electricity in GJ (10):

$$VeGJ = Bg * 22/1000 \tag{10}$$

According to Akbulut [37], his study serves as a basis for determining the daily thermal energy production, according to which 1 m^3 of biogas results in the production of 2.47 kWh of thermal energy. The formula (11) for the calculation of the produced thermal energy is the following, which can also be expressed in other breakdowns such as weekly, monthly, or yearly:

$$HeMWh = Bg * 2.47/1000, \tag{11}$$

where: H_{eMWh} denotes the production of heat energy. We divide the result of the product of the reference value 2.47 and B_g by 1,000 to express kWh in MWh. On the other hand, when calculating the result of the available heat energy that approximates the reality, 10% must be deducted from the H_{eMWh} value, as this is used by the plant for its own operation.

3. The degree of energy self-sufficiency was analysed based on the heat and electricity usage analysis of the examined company family, and the company provided the data on the group's electricity and natural gas consumption (MWh).

In terms of electricity, in addition to data on the energy consumption of meat processing and slaughterhouses, data on other points of consumption were also provided. The consumption indicators come from previous years in a monthly breakdown and in the case of electricity also in a daily breakdown. Also, it was estimated as to what extent it could provide energy for the other economic activities of the surrounding industrial park: a board price and drying plant, a milk factory, etc.

4. The amount of greenhouse gases from the livestock by-product of pig fattening, and its impact on the environment, expressed in tons/year in relation to carbon dioxide (CO_2) and sulphur dioxide (SO_2). The calculation was realized based on reference values from the study done by Dourmad [38], simultaneously with eutrophication (algae and swamping of waters). This method used the following formula (12):

$$Kh = S * \text{á}.t. * r.\text{é}./1000, \tag{12}$$

where: K_h represents the annual load on the environment (e.g. CO_2), S represents the number of pigs (11,500), á.t. denotes the average weight per animal (70 kg), and r.é. denotes the reference values described in the aforementioned study, based on 1 kg pig live weight. The division is necessary so that the value is expressed in tons for an easier understanding.

Another greenhouse gas, methane (CH_4), also requires increased attention. Quantifying its release into the atmosphere is very difficult, so we approach it from the point of view that the raw material used in the biogas plant (e.g. pig slurry) can release around 60% of methane during optimal intensive fermentation processes [39]. Of course, this can only be achieved in fermentation units, as liquid manure stored outdoors does not release such a large amount into the atmosphere.

5. The investment budget was based on a detailed study [37].

The realization of the construction of the biogas plant requires two types of investment: one is the so-called capital expenditure (CAPEX), which the company pays once during the implementation process, and the other investment is operational expenditure (OPEX), which must be continuously financed beyond the construction of the plant [40].

6. Calculation of return and yield data based on the cost of the investment and the value of the heat and electricity produced. Before the start of the investment, the net present value (NPV) must be calculated, which can be used to decide whether or not the investment is worthwhile. If NPV > 0, then we can implement the investment, whereas if < 0, then we do not implement it because it will be unprofitable. The formula for its calculation is (13):

$$NPV = \sum_{t=0}^{N} \frac{C_n}{(1+r)^n} - C_0, \tag{13}$$

where: C represents the sum of cash flows, n denotes each period, N represents the holding period, and r represents the desired target yield or denotes the required rate of return [41]. Calculating the payback period, the Bioenergy for Business Software [42] was used with a 25-year perspective.

7. Carrying out and presenting the economic calculations of sustainable biogas operation.

8. Examination of the social, health, and sustainability effects of the investment on the local and microregion.

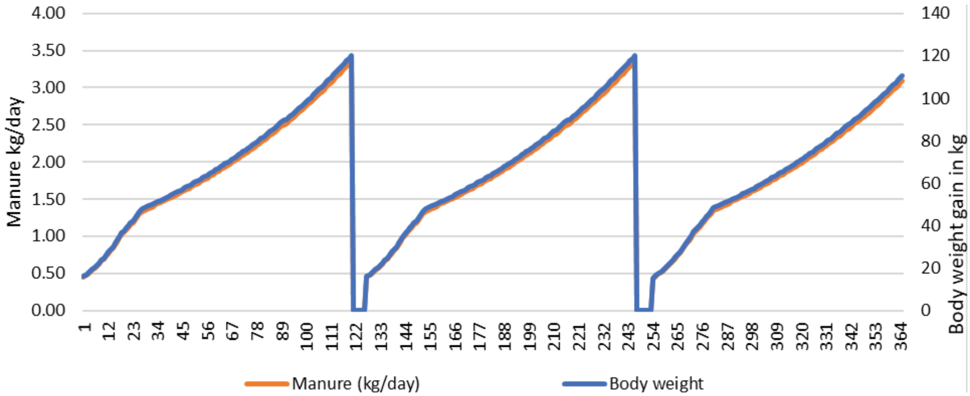
3. Results and discussion

3.1. Biogas production assessment

Firstly, we are going to present the research site, namely the Toro Impex Ltd, established in 1991, whose main activity was the operation of a slaughterhouse and meat processing plant in the village of Lemnia in the north-eastern part of Covasna County in Romania. In 2007, thanks to a SAPARD co-financed investment project, the company constructed a new slaughterhouse. The modern enterprise began to develop rapidly into a modern pig, sheep, and cattle slaughterhouse and processing plant that meets the expectations. Additionally, between 2014 and 2016, a pig farm was also constructed with a capacity of 3,600 pigs, which can realize 3 breeding cycles annually. Along this, cattle breeding takes place within this agro-food company. Agricultural activities are also part of the company's activities, growing crops on more than 100 hectares. Livestock-feeding activities produce main field crops such as corn, wheat, and other cereals, and tens of hectares of mowing fields are used for the seasonal grazing of animals. The machine park is well equipped, but in order to maintain it, it also operates a well-equipped service workshop with qualified personnel. Thus, they undertake to repair the equipment of the farmers in the area [43].

At the pig-breeding site, 3,600 pigs are raised to slaughter weight in each cycle, which means from an initial state of 16–25 kilograms to a state of 90–120 kg in around 100 days, amounting to 10,800 pigs per year. Between each cycle, there are a few days (approx. 7) during which there are no pigs in the buildings, which is when the area is sanitized and preparations are made for the arrival of the next round of pigs. The number of empty days can be increased up to 25 days per year.

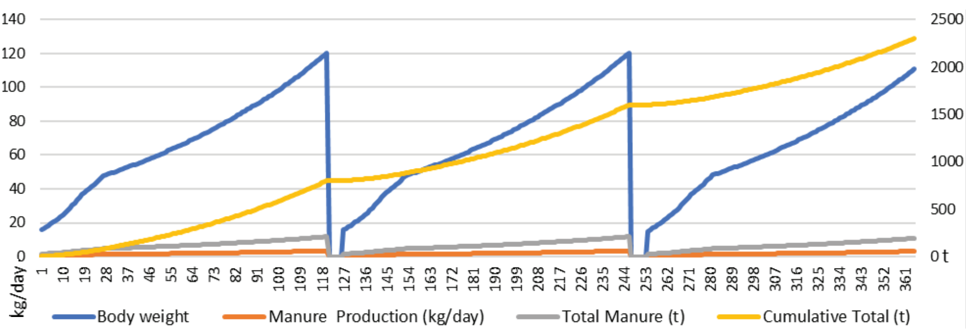
According to [44], we know that an average pig weighing 70 kg produces 2.09 kg of liquid manure per day. Using the rule of three, it can be calculated that a pig with an initial weight of 16 kg entering the farm produces 0.447 kg of liquid manure per day. The daily body weight gain per pig is shown in parallel with the daily slurry production in the diagram below (*Figure 1*).



Source: authors' calculation

Figure 1. The annual trend of pig body weight development and slurry training

On the farm level, the daily manure production of pigs in an annual projection is illustrated in *Figure 2*. The weight of the pigs from the beginning of the breeding cycle to the 18th day grows 1.05 kg/day, from the 19th to the 27th 1.03 kg/day, and from the 28th day to slaughter weight 1.01 kg/day [45]. Knowing the average daily weight of the pigs and the amount of daily liquid manure production calculated from this using the rule of three, together with the empty days, approximately 2,304.52 tons of liquid manure is produced as a by-product of the 10,800 pigs.



Source: authors' calculation

Figure 2. Annual dynamics of the pigs' body weight gain and liquid manure production

Based on our research, through the following steps, we designed the biogas production at Toro Impex Ltd, as well as the potential energy and power consumptions:

1. Preparation of raw materials: pig and cattle manure, silage and agricultural waste, and wastewater from the slaughterhouse are collected and pumped to the pre-storage.

2. Pre-treatment and storage: The pre-treated fluid manure is placed in a solid biomass tank, where it undergoes further processing. The material is processed into a homogeneous mixture; the solid biomass is processed with an energy consumption of 11 kWe.

3. Fermentation units: The mixture is sent to the first fermentation unit, where anaerobic fermentation takes place at a temperature of 44 °C. During fermentation, microorganisms break down organic materials, producing biogas and fermentation residues.

4. Secondary fermentation: The biogas and the fermentation residue pass on to the second fermentation unit, where the decomposition process continues at 38 °C, with an additional 18.5 kWe of energy consumption. This stage is used to increase the yield of biogas.

5. Fermentation tank: fermented residues are sent to a large fermentation tank, where the final decomposition processes take place. The entire process requires an energy consumption of 30 kWe.

6. Biogas storage and utilization: the generated biogas is collected in a biogas storage tank with a capacity of 250 m^3. The stored biogas can be used for various purposes.

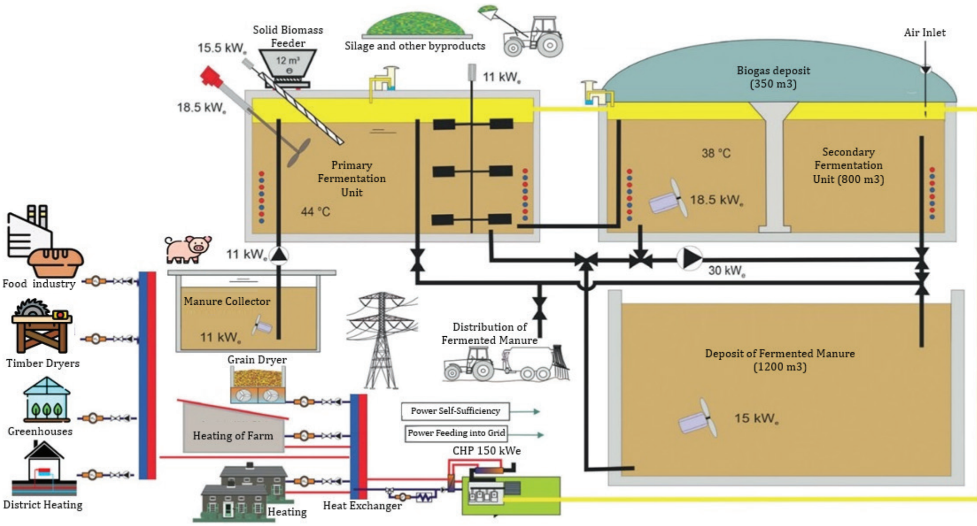
7. Electricity production: biogas is burned in a cogeneration (CHP) unit, which produces electricity and heat. The cogeneration unit operates with a total capacity of 450 kW, of which 150 kWe of electricity and 300 kWth of heat energy are generated.

8. Electricity and heat distribution: the generated electricity is used in farms and slaughterhouses, and the leftover will be fed into the electrical grid for use by consumers such as residential buildings, industrial facilities in surroundings, and public institutions. The generated heat is used in heating systems such as district heating networks.

9. Utilization of fermented residue: The solid and liquid materials remaining after fermentation are distributed to agricultural lands, where they serve as a valuable soil conditioner, improving soil fertility.

In summary, *Figure 3* shows the complex process of biogas production, which includes the preparation of raw materials, fermentation, storage and utilization of biogas, and the environmentally friendly treatment of residual materials.

The results of the annual calculation of the daily biogas production of 3,600 pigs raised at the same time show that an average of 2,525.48 m^3 of biogas is produced per day. The average of the weekly biogas generation is 17,678.36 m^3, while the annual data show a 921,800.2 m^3 of biogas production.

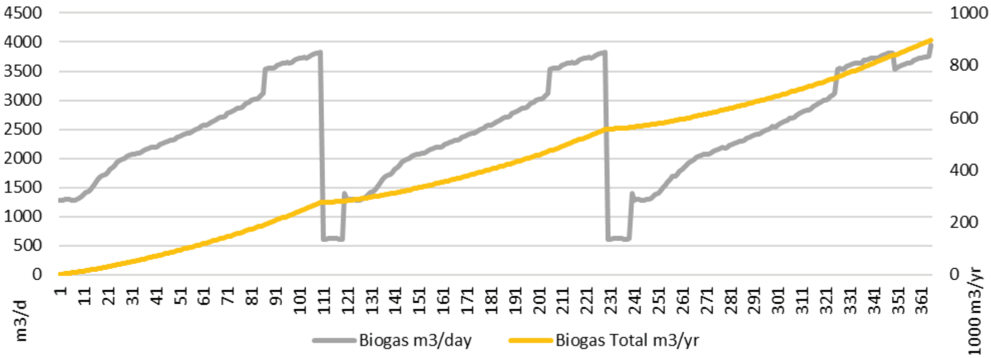


Source: authors' calculation

Figure 3. Flowchart of the biogas production and energy consumption

The breeding of approximatively 60 cattle, based on the study of [46], produces 29.5 kg of liquid manure per individual per day, which means 1.77 tons of liquid manure per day in total, an estimation also confirmed by the farm. This amount of liquid cattle manure produces 720 m^3 of biogas per day, 5,040 m^3 per week, 21,600 m^3 per month, and 262,800 m^3 per year.

The slaughterhouse and the meat-processing plant use a significant volume of hot water during their operation, and as a result the generation of wastewater is outstanding. Based on realistic data provided by the company, the plant has a daily processing capacity of 200 pigs and 50 cattle. The average weight of 200 pigs going to the slaughterhouse is 98 kg while that of 50 cattle is 300 kg, which means 19.6 tons of processed pigs and 15 tons of cattle per day. In order to determine the resulting daily amount of wastewater, the weight of pigs must be multiplied by 2, while the weight of cattle must be multiplied by 5 [47], based on which 114.2 m^3 of wastewater is generated (the slaughterhouse does not operate on weekends). According to [34], approximately 0.2 m^3 of biogas can be produced from 1 m^3 slaughterhouse wastewater with proper fermentation. Projected for the plant in Lemnia, this means 22.84 m^3 per day, 114.2 m^3 per week, 525.32 m^3 per month, and 5,961.24 m^3 per year of biogas production. In total, it means a biogas production of an average of 2,479.84 m^3/day, an average of 75,428.37 m^3/month, and 905,140.55 m^3/yr. The production dynamic of the biogas can be seen in the graph below (*Figure 4*) broken down into days in annual terms.



Source: authors' calculation

Figure 4. Daily and cumulative annual dynamic of biogas production

3.2. Assessment of energy and power consumption

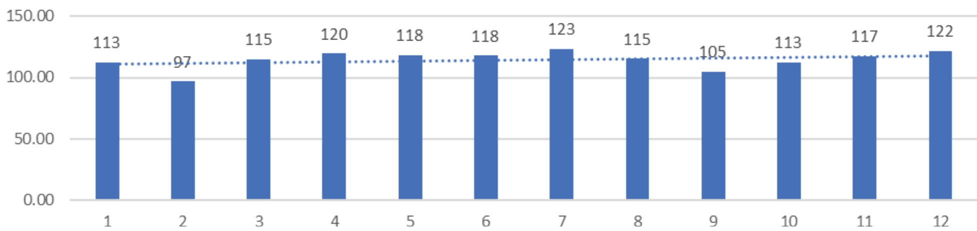
The company provided accurate data on the electricity and gas consumption of the slaughterhouse and meat-processing plant (*Table 1*).

Table 1. Annual power consumption of the company in total and in different consumption locations (MWh)

Location	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Bretcu	0.35	0.54	0.43	0.45	0.70	0.42	0.41	0.33	0.45	0.72	0.25	0.42	**5.47**
Oituz	6.46	7.79	7.80	7.98	6.20	7.07	6.25	8.20	6.30	7.70	6.88	7.42	**86.05**
Bretcu 2	3.20	3.21	3.00	2.72	3.02	2.22	2.86	3.11	2.60	2.68	3.21	3.42	**35.25**
Târgu Secuiesc	1.64	0.38	1.20	1.32	0.90	2.35	2.63	0.88	1.34	2.88	2.11	2.99	**20.62**
Lemnia 1	2.00	1.69	2.20	2.30	2.45	3.01	3.30	2.45	1.98	2.23	3.12	3.22	**29.95**
Lemnia 2	1.50	1.00	1.34	1.50	1.70	1.50	1.66	1.21	1.32	1.43	1.73	1.42	**17.31**
Mereni	2.45	2.07	2.22	2.45	2.80	2.62	2.69	2.40	2.32	2.86	2.02	2.86	**29.76**
Lemnia 3	95.00	80.10	97.00	101.00	100.68	98.63	103.38	96.80	88.30	92.20	98.13	99.76	**1,150.98**
Total	**112.60**	**96.78**	**115.19**	**119.72**	**118.45**	**117.82**	**123.18**	**115.38**	**104.61**	**112.70**	**117.45**	**121.51**	**1,375.39**

Source: Toro Impex Ltd

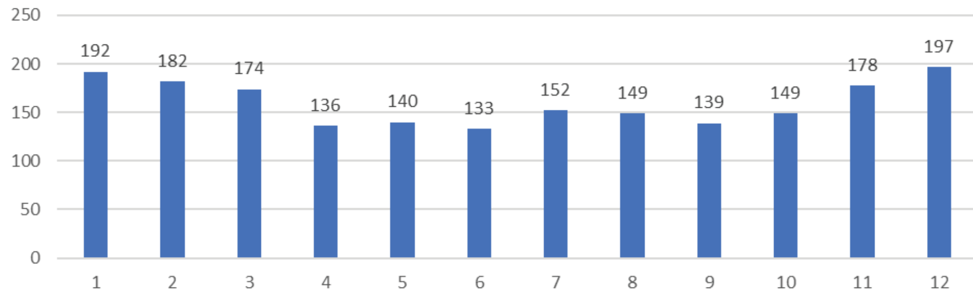
Broken down into 12 months of the year, the electricity consumption of the above-mentioned locations can be seen in *Table 1*. On average, the consumption is 114.62 MWh per month, and summing up the electricity consumption of the months on an annual basis, the result is 1,375.39 MWh. Of this energy use, the slaughterhouse and the meat processor consume 1,128 MWh hours (*Figure 5*).



Source: authors' calculation

Figure 5. Monthly power consumption at Toro Impex Ltd

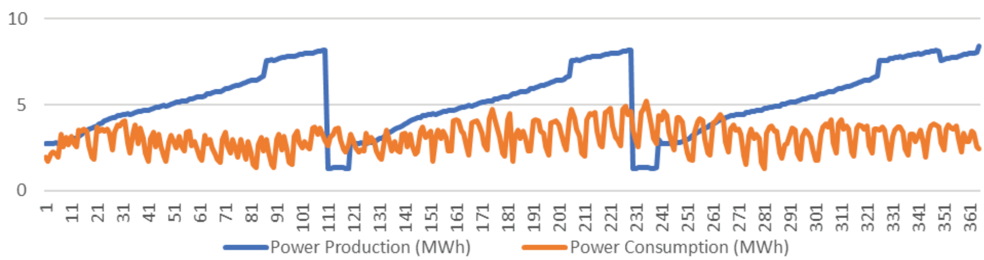
For heating purposes, the slaughterhouse and the meat processing plant currently use natural gas (*Figure 6*), which generates an average monthly consumption of 159.88 MWh, as can be seen in the diagram. In total, 1,918.56 MWh of natural gas is used annually.



Source: authors' calculation

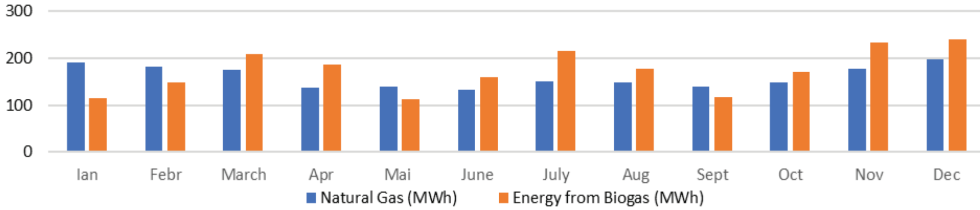
Figure 6. Monthly natural gas consumption (MWh) at Toro Impex Ltd

The potentially produced amount of biogas (m3) can be converted into electricity or thermal energy. The energy yield of biogas that can be produced in a daily breakdown is 4.04 MWh/day and in annual terms approximately 1,917 MWh/year (*Figure 7*). The following figure (8) shows a monthly breakdown of the thermal energy potentially produced from biogas and the demand for natural gas for energy production, expressed in MWh.



Source: authors' calculation

Figure 7. Daily and annual power consumption and production in MWh



Source: authors' calculation

Figure 8. Thermal energy demand covered by natural gas and potentially produced biomass in MWh

3.3. Assessment of biogas investment

Table 2 summarizes the elements required for the operation of the biogas plant. The costs listed in the table include the capital costs (CAPEX) of the biogas plant, which means the initial investment costs required to establish the plant. These costs cover physical assets, infrastructure, and construction works alike. The details of each item are as follows:

1. Assets: EUR 371,956.39

– This amount includes the basic equipment and machinery required for the operation of the biogas plant. These may include the various mechanical and electrical systems that ensure the efficient and safe operation of the plant.

2. Earthwork/Landscaping: EUR 33,896.76

– The costs of earthworks and landscaping include the work necessary to prepare the construction of the plant. This includes site preparation, foundation, and proper drainage systems.

3. CHP Turbine: EUR 263,305.17

– Costs of a combined heat and power (CHP) turbine. The CHP unit plays a key role in the use of biogas, as it enables the efficient production of electricity and heat from biogas.

4. Heating network: EUR 75,662.41

– The costs of building the heating network. This system is used to transport the thermal energy produced by the CHP unit, which is used to heat the facility and possibly the surrounding community.

5. Electricity connection: EUR 15,132.48

– This amount includes the costs of connecting the biogas plant to the electricity system, including the installation of the necessary cables and transformers.

6. Primary fermenter: EUR 151,324.81

– Costs of the primary fermentation unit. In this equipment, the first phase of anaerobic fermentation takes place, during which the production of biogas begins.

7. Secondary fermenter: 211,854.74 EUR

– Costs of the secondary fermentation unit. This unit performs the second phase of fermentation, in which the efficiency of biogas production continues to increase.

8. Fermentate tank: EUR 90,794.89

– Costs of a deposit for storing fermentation residues. This container ensures the safe storage and subsequent utilization of the remaining materials.

9. Pump units: EUR 121,059.85

– Costs of various pumps and pumps used to move raw materials, fermentation residues, and biogas between different parts of the plant.

Total: 1,334,987.50 EUR

The total investment cost, which includes all the items mentioned above, is detailed in *Table 2*. This amount shows the total capital investment required to establish the biogas plant.

These costs are crucial for the successful installation and operation of a biogas plant, as they provide the necessary infrastructure and equipment for the efficient production and utilization of biogas. An accurate definition and optimization of individual items is essential to ensure the economic viability of the project.

Table 2. CAPEX of the biogas plant

CAPEX	**EUR**
Equipment	371,956.39
Earthwork/Landscaping	33,896.76
CHP Turbine	263,305.17
Heating demand	75,662.41
Power connection to grid	15,132.48
1st fermentation	151,324.81
2nd fermentation	211,854.74
Deposit of fermented residuals	90,794.89
Pump stations	121,059.85
Total	1,334,987.50

Source: authors' calculation

Table 3 shows the annual costs beyond the construction of the plant, expressed in euros:

– Personal expenses: 14,500.00 EUR

This amount includes the full annual cost of staff wages, benefits, and other related expenses required to operate the plant.

– Biogas CHP Maintenance: 1,499.62 EUR

This cost is the sum of the annual expenses related to the maintenance of the biogas cogeneration plant (CHP). This includes replacement of parts, repairs, and preventive maintenance activities.

– Fermenter maintenance: 2,999.25 EUR

The fermenter, which performs the anaerobic fermentation process, requires regular maintenance. This item includes cleaning, replacement of parts, and other maintenance tasks.

– Control and inspection: EUR 2,250.00

This amount covers the operating and maintenance costs of the control and monitoring systems of the biogas plant. This includes software updates, hardware maintenance, and regular checks.

Total: 21,250.00 EUR

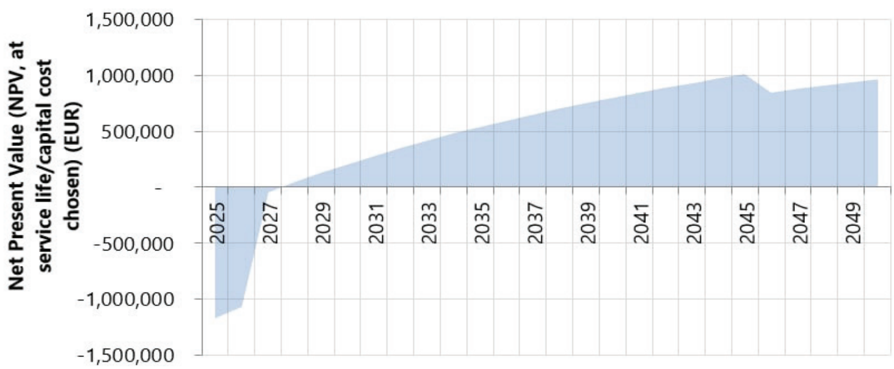
The above costs reflect in detail the main expenses that are necessary for the annual operation and maintenance of the biogas plant.

Table 3. OPEX of the biogas plant

OPEX	**EUR/Yr**
Personal costs	14,500.00
Maintenance of Biogas CHP	1,499.62
Maintenance of fermentation	2,999.25
Monitoring and control system	2,250.00
Total	21,250.00

Source: authors' calculation

The calculation of the payback period of the biogas plant was made possible by the use of the Bioenergy for Business Software. Including all costs (also annual maintenance costs), the payback period can be set at 3.2 years, as shown in the diagram created below, as well as the net present value was calculated for a period of 25 years; its dynamic is shown in *Figure 9*.



Source: authors' calculation

Figure 9. Calculation of the payback period and net present value in 25 years dynamic

3.4. Assessment of the environmental impact of the investment

The table below (4) shows the amount of CO_2, SO_2, and CH_4 released into the atmosphere and the degree of eutrophication in the case of untreated slurry, expressed in tons on an annual basis; in other words, with the establishment of the biogas plant, 1,812 t/year CO_2, 35 t/year SO_2 greenhouse gas enters the atmosphere, and the eutrophication of waters would decrease by 15 t/year compared to the (current) state before the establishment of the biogas plant.

On an annual basis, during the operation of the biogas plant, an average of 1,487.63 m^3 per day and approximately 364,345 t/yr of methane are produced. In the case of liquid manure stored in untreated form, methane emissions would not be as high, but a large part of this amount would be released into the atmosphere, further increasing the greenhouse effect.

The fermented residue produced during the production of biogas can be used as a valuable soil conditioner, which improves the fertility of agricultural land with its high nutrient content. In addition, biogas plants can contribute to improving waste management by recycling agricultural and municipal waste, thereby reducing the burden on landfills and environmental pollution from waste [48].

The establishment of the biogas plant leads to the creation of new jobs, which contributes to the revitalization of the local economy and the reduction of unemployment. The workforce needed to run the plant can be sourced from local residents, thereby strengthening the economic stability of the community. In addition, during the establishment of the plant, local businesses can also benefit from the construction and maintenance work, which further strengthens the local economy.

The biogas plant can significantly contribute to alleviating odour problems in the environment. During the fermentation processes, raw materials such as liquid manure and sewage decompose anaerobically, so no unpleasant odour is produced. This can result in a significant improvement in the quality of life of local residents, especially those living in the immediate vicinity of the plant.

Table 4. The effect of raw slurry on the environment

	Total value for Toro Impex Ltd t eq.	**Ref. value for 1 kg life weight *[49]***
Carbon dioxide (CO_2)	1,812	2.251
Sulphur dioxide (SO_2)	35.42	0.044
Methane (m^3 CH_4)	364,345	
Eutrophication	15,295	0.019

Source: authors' calculation

The operation of the biogas plant provides a sustainable source of energy that can cover the plant's own heating and electricity needs and can even produce surplus energy. This can lead to reduced energy use and reduced demand for fossil fuels. Self-sustainable energy supply reduces dependence on external energy sources, increases energy security, and contributes to combating climate change by reducing greenhouse gas emissions.

4. Conclusions

Building on the hypotheses, the establishment of a biogas plant at Toro Impex Ltd offers a comprehensive solution to meet the company's energy needs while simultaneously addressing environmental, economic, and social objectives. The utilization of pig manure and slaughterhouse residues as primary feedstock for biogas production aligns with the enterprise's goal of achieving energy self-sufficiency. The conversion of these organic materials into biogas is expected to generate sufficient electrical and thermal energy to support the diverse operations of the enterprise. This energy autonomy reduces the dependency on external supply, thereby enhancing the company's resilience to energy market fluctuations and supply disruptions.

In addition to meeting the company's internal energy demands, the biogas plant is projected to significantly mitigate environmental impacts. One of the most critical environmental benefits is the substantial reduction in odour pollution, a common issue associated with pig farming and slaughterhouse operations. The anaerobic digestion process not only controls these odours but also prevents the release of large quantities of greenhouse gases (GHGs), particularly methane, into the atmosphere. This reduction in GHG emissions contributes to the mitigation of climate change, positioning Toro Impex Ltd as a responsible entity that actively participates in environmental stewardship and local ecosystem preservation [50].

The energy generated by the biogas plant extends beyond the company's immediate needs. The hypothesis posits that any excess electricity produced will be fed into the national grid, thus creating a valuable additional revenue stream for Toro Impex Ltd. This surplus electricity generation not only supports the financial viability of the biogas plant but also contributes to the broader energy infrastructure by providing clean, renewable energy to the grid. Additionally, the thermal energy generated, which might exceed the farm's requirements, can be utilized by neighbouring industrial sites with high heat demands. This strategic use of thermal energy fosters industrial cooperation within the local community and creates opportunities for economic synergies, further strengthening the local economy.

The post-fermentation digestate, a by-product of the biogas production process, offers substantial agricultural benefits, aligning with the hypothesis that it will serve as a high-quality, mature organic material for crop fertilization. The application of this nutrient-rich digestate to agricultural fields has the potential to significantly improve soil quality compared to the use of raw manure. By enhancing soil fertility, the digestate reduces the need for chemical fertilizers, which not only lowers agricultural input costs but also minimizes the environmental impacts associated with synthetic fertilizers such as soil degradation and water contamination. This shift towards organic fertilization represents a significant advancement in sustainable agricultural practices within the region.

Moreover, the biogas plant is expected to generate new employment opportunities, which aligns with the hypothesis that it will contribute to the creation of a local energy community. The jobs created during both the construction and operational phases of the plant will provide economic benefits to the local community, reducing unemployment and enhancing economic stability. The development of a local energy community, supported by the biogas plant, fosters energy autonomy by reducing reliance on imported energy [51]. This autonomy not only stabilizes the local energy supply but also positions the community to better manage energy resources in times of economic or geopolitical uncertainty.

In conclusion, the biogas plant project at Toro Impex Ltd is poised to deliver on the hypothesized benefits, including achieving energy self-sufficiency, reducing environmental impacts, generating additional revenue, improving soil quality, and fostering local economic development. The integration of these outcomes underscores the strategic importance of the biogas plant as a cornerstone of sustainable development for the company and the surrounding community. By leveraging the plant's potential to transform waste into valuable resources, Toro Impex Ltd will not only enhance its operational efficiency but will also contribute to the long-term sustainability and prosperity of the region.

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Evaluation of agrodiversity in the oasis agroecosystems of the Béni-Abbès region (southern Algeria)

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Abstract. This study is a contribution to the assessment of agro-diversity in traditional agro-systems of the wilaya of Béni-Abbès (southern Algeria). It made it possible to carry out an inventory of local varieties, crops grown, and traditional know-how. The study is based on field investigations and surveys conducted among oasis farmers. These surveys, structured in the form of questionnaires, made it possible to collect data on agro-biodiversity and the socio-economic aspects of traditional oasis agro-ecosystems. In total, 54 oasis farmers were interviewed in order to collect and characterize the local phytogenetic heritage of the species cultivated in the three studied oases. The results of the surveys and the systemic analysis of the data collected show a remarkable diversification of speculations, with more than 44 different crops recorded, represented by 15 market garden species, 10 cereal and fodder species, 19 condiment, medicinal, and aromatic plants, 5 fruit species, and 5 date palm cultivars among the most consumed. This diversification is also observed in animal production, with a diversity of species (goats, sheep, and poultry). These oases are characterized by the practice of mixed farming and present a remarkable diversity of genetic resources of fruit trees, market garden crops, fodder crops, and local cultivars adapted to arid, dry, and extreme agro-ecological conditions. The inventory carried out on agro-biodiversity constitutes a key element of sustainability and an original database on existing varietal diversity in order to propose appropriate actions for the safeguarding and conservation of this genetic heritage of oasis agroecosystems.

Keywords: diversity, agro-system, inventory, sustainability, oasis, Algeria

1. Introduction

Oases are anthropized spaces cultivated by intensive agricultural activity within vast arid and desert areas. They are distributed in most of the large dry regions of the world: around the Sahara, in the Maghreb and the Sahel, in the Middle East, on the west coast of Latin America, and in Central Asia [1–3].

For a long time, the inhabitants of the oases have developed their cultures in contact with the plants that they continue to use for several purposes: food, medicine, energy. Plant genetic resources for agriculture constitute the biological basis of local food security and provide livelihoods for all the inhabitants of the region. They represent one of the fundamental elements of the sustainability of the oases and constitute an important natural bulwark against the various factors of degradation of the oasis ecosystem [4–6]. For the oases, plant genetic resources are one of the attributes of their sovereignty and a permanent source of supply to meet their increasingly diversified, dynamic, and growing needs. Agricultural products and by-products are today a major challenge for a population in full demographic growth [6]. Oases play a crucial role in human societies and the conservation of biodiversity, especially in harsh environments like arid zones. They serve as sanctuaries for agrodiversity, preserving diverse agricultural resources under challenging climatic conditions [7].

In North Africa, oasis agroecosystems cover approximately 380,000 hectares, which represents cc. 32.4% of the oases in the Middle East and the North African region [8]. In Algeria, oases are distributed in 17 wilayas, ranging from the north of the Sahara (southern limit of the steppe) to the far south. The oases occupy an area of more than 180,000 ha with more than 1,100 cultivars of date palms recorded and an annual date production of around one million tons [9–10]. Oases are part of Algeria's natural and heritage wealth.

However, Algerian oases have been experiencing a loss of agro-biodiversity for several decades, which continues to accelerate. Indeed, they are now faced with numerous socio-economic and agro-ecological threats and constraints (abandonment, conflicts of use, inheritance, excessive fragmentation, urbanization, tourism, climatic hazards, aridity, silting, wind and water erosion, genetic erosion, water scarcity, monoculture, salinization of groundwater and soils, the ravages caused by certain diseases such as Bayoud, rural exodus), which contribute to increasing their vulnerability and leading to the disappearance of traditional oases [3, 6, 11, 12].

Faced with this situation, the prospection, conservation, and reintroduction of the phytogenetic heritage of the oases are essential to preserve their agrobiodiversity. Senoussi et al. [11] indicate that one of the sustainability factors of the oasis agrosystem is the variability of its genetic resources, both floristic and faunal. The ecological diversity of the Algerian Sahara is at the origin of a diversification of palm groves, exploitation and management models appropriate to each type of oasis, and its human component. The objective of this study is to inventory and evaluate the existing agrodiversity in the oasis agrosystems of the wilaya of Béni-Abbès (southern Algeria).

2. Materials and methods

Study area

The wilaya of Béni-Abbès, located in the extreme southern of Algeria in the Saoura region (*Figure 1*), has been the capital of a new wilaya since 2021. It covers an area of 112,000 km² and is home to a population of 60,000 inhabitants with a density of 1.1 inhabitants/km² [13].

It is bordered to the north by the wilaya of Béchar, to the east by Timimoune and Adrar, to the west by the Kingdom of Morocco and Tindouf, and to the south by the wilaya of Adrar. It contains twenty-eight oases across its vast territory, with a total area of the oases of the Béni-Abbès region. Farmers practise agriculture on a total of 546 oases [14].

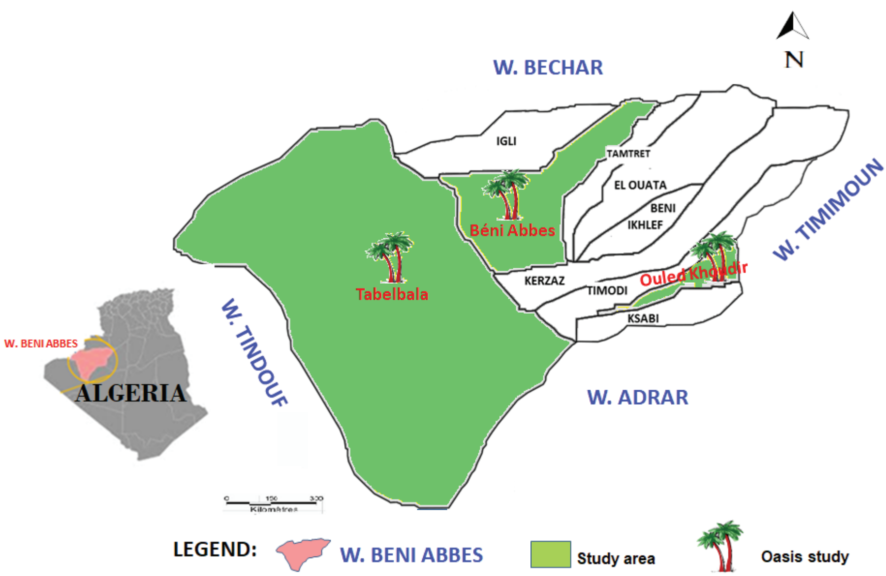

Figure 1. Geographical location of the study area (wilaya of Béni Abbès)

Choice of study stations

The choice of the three studied oases fell on Tabelbala, Béni-Abbès, and Ouled Khoudir following a north, centre, and south transection. These three oases are considered representative of the agroecological diversity of the wilaya of Béni-Abbès. These ancient oases were selected for their diversity and the traditional techniques developed by the Ksourian population (*Table 1*).

– Oasis of Tablebala, in the commune of Tabelbala, covers a total area of 400 ha. The population is 25,992 inhabitants. The climate is of the continental Saharan type with temperate winters.

– Oasis of Béni-Abbès, in the commune of Béni-Abbès, covers an area of approximately 42 ha. It has a hyper-arid Saharan climate characterized by low precipitation that hardly exceeds 50 mm/year.

– Oasis of Ouled Khoudir, in the commune of Ouled Khoudir, covers an area of approximately 541 ha. The climate is dry Saharan with a continental tendency. Annual precipitation is rare and irregular, not exceeding 80 mm, and the temperature can reach 45 °C in the summer.

Table 1. Geographic coordinates of the studied oases

Oasis	**Béni-Abbès**	**Tabelbala**	**Ouled Khoudir**
Latitude	30°7’60”N	29°24’22”N	29°15’16”N
Longitude	2°10’0”W	3°15’33”W	1°3’27”W
Altitude (m)	499	518	380
Area (ha)	42	400	541

Methodological approach

In order to know the situation of the oasis systems of the wilaya of Béni-Abbès, located in southern Algeria, we carried out a diagnosis of the different agricultural land exploitation systems.

a. Conducting the surveys

The assessment and inventory of oasis agrodiversity were based on the technique of semi-directed surveys using questionnaires designed for this purpose. A total of 55 farmers were surveyed and investigated in the three oases of the Béni-Abbès region during the period of March 2021 – June 2022. In each oasis, surveys were conducted with a sample of 20% of the farmers (*Table 2*).

The prospection and inventory of the phytogenetic resources of the three studied oases aim to assess the specific diversity of the three levels (phoenicicole, fruit and herbaceous arboreal: market gardening, fodder, industrial crops). This will also enable the characterization of the different production factors: surface area of the farms, types of crops, cultivation practices, cultivars, number of date palms, sources and frequency of irrigation, fertilization, labour, animal production, and the parameters for measuring fruit agrodiversity (specific richness, varietal richness).

The surveys of farmers are structured by a questionnaire that guides the interviews and includes aspects relating to agrodiversity and socioeconomics. The importance of each speculation is assessed by estimating the surface area per farm of each crop, the percentage of each crop in relation to the total surface area of the farm, and the ratio between the surface area of each crop and the total surface area reserved for crops on each farm surveyed.

Table 2. Number of farmers surveyed in the studied oases

Oasis	Béni-Abbès	Tabelbala	Ouled Khoudir	Total
Number of farmers	60	80	133	273
Number of farmers surveyed	12	16	27	55

b. Analysis of the surveys

A careful analysis of the questionnaires will facilitate our subsequent data analysis. The analysis consists of displaying all the parameters and indicators taken into consideration for each site surveyed. The survey data are processed by the Microsoft Excel software.

3. Results and discussions

3.1. Analysis of some production parameters

a. Areas and land status of the farms

In the studied oases, the cultivated plots are of small size, with an average area exploited per farmer of around 1.3 hectares. The plots cultivated by farmers in the oasis of Béni-Abbès have an average area of 1.26 ha, of which 83% are exploited by a mixed type in crops and livestock. In the oasis of Ouled Khoudir, the average area is 1.09 ha: 74% of the farmers surveyed are of the mixed type (grow crops and breed livestock), and 89% are of the owner-inheritance type. In the oasis of Tabelbala, the average area is 1.2 ha, of which 100% are of the mixed type combining plant and animal production (*Table 3*).

The majority of the farms are of the family inheritance type, which is to say there is a joint land ownership (passed down in the family), with 75% of the farms in the two oases of Béni-Abbès and Ouled Khoudir and 89% of inherited farms in the 3rd oasis, of Tabelbala. This predominance of micro-plots exploited, of reduced size by small owners of a family nature, generally in joint ownership, indicates a significant fragmentation of production units (0.5 to 1.5 ha/farmer) in all of the oases.

Table 3. Characterization of farm production in the studied oases

Oasis	**Béni-Abbès**	**Tabelbala**	**Ouled Khoudir**
Average farm area (ha)	1.26	1.2	1.09
Owner type (inheritance)	75%	75%	89%
Investment	25%	13%	15%
Crops (plant production)	17%	74%	25%
Mixed (crops and livestock)	83%	100%	0%

The fragmentation of land, due to the transmission of inheritances, has led to a drop in farmers' income. This situation has also been noted in previous works on oasis agrosystems [15–18]. Indeed, excessive land fragmentation in these oases has a direct negative impact on agricultural productivity, access to means of production, and farmers' incomes, compromising the sustainability of these oasis systems. Policies of land consolidation or incentives for the grouping of plots may be necessary to improve this situation.

b. Demographic analysis of operators (age, gender, and academic level)

The survey was conducted among 55 farmers in the three studied oases. The average age of the farmers was 48, 53, and 54 years of age in the oasis of Béni-Abbès, the oasis of Ouled Khoudir, and in Tabelbala respectively. The population covered by the surveys is relatively old. This choice aims to interview experienced people, with considerable agricultural know-how.

The academic level shows that the illiteracy rate is high, ranging from 38% to 44% depending on the oases: 42% in Béni-Abbès, 44% in Ouled-Khoudir, and 38% in Tabelbala. Secondary education levels vary from 22% to 33% depending on the oases: 33% in Béni-Abbès, 22% in Ouled Khoudir, and 31% in Tabelbala (*Figure 2*).

Concerning the gender-based division of labour among the respondents, men (90%) practise the various agricultural works on the farms (ploughing, planting, irrigation), and women (6%) carry out certain secondary works (harvesting, small livestock, etc.).

These elements highlight the challenges faced by farmers in these oases, particularly in terms of land fragmentation, small cultivated areas, and a relatively low level of education.

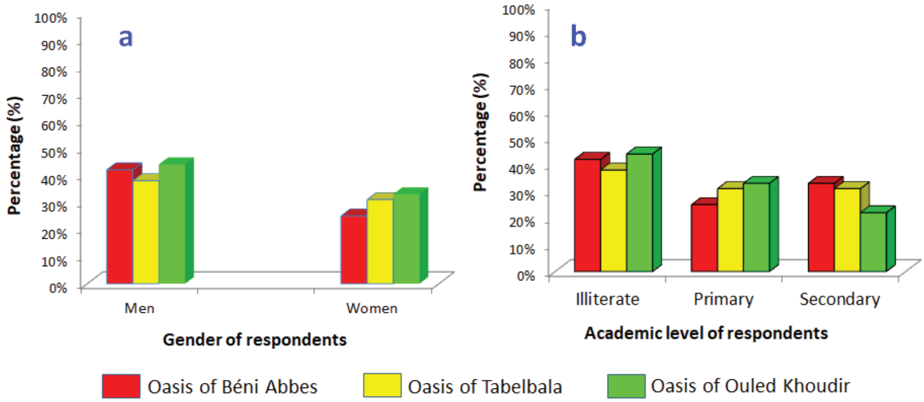

Figure 2. Demographic characterization of respondents in the studied oases (a. gender, b. academic level)

The agricultural practices of local populations are part of the cultural heritage accumulated throughout the history of the region, in the face of a hostile desert climate. This refers to the ancestral knowledge and techniques used by local populations in their agricultural activities. This know-how is the result of long experience and adaptation over time to a hostile desert environment. It is an integral part of the cultural heritage of this region.

Older farmers are very important sources of know-how, but they have a low potential for developing oasis agricultural activities.

3.2. Irrigation

Water resources and irrigation practices vary significantly between the three studied oases (*Figure 3*).

In the oasis of Béni-Abbès, 67% of the farmers use wells for irrigation, with a water cycle of 83 minutes and a frequency of twice a week. In the oasis Ouled Khoudir, the duration of the water cycle is 75 minutes, with an irrigation frequency of once a week (67%), where 85% of the irrigation source comes from wells, compared to 15% from boreholes. For the Tabelbala oasis, the duration of the water cycle is 80 minutes, with an irrigation frequency of once a week (50%), where 44% of the irrigation source comes from wells, compared to 56% from borehole water (*Table 4* and *Figure 5*).

These different strategies show that farmers adapt to the specificities of their oasis, taking account of the available water resources (wells, boreholes) and by accordingly adjusting the frequencies and durations of irrigation [19–21].

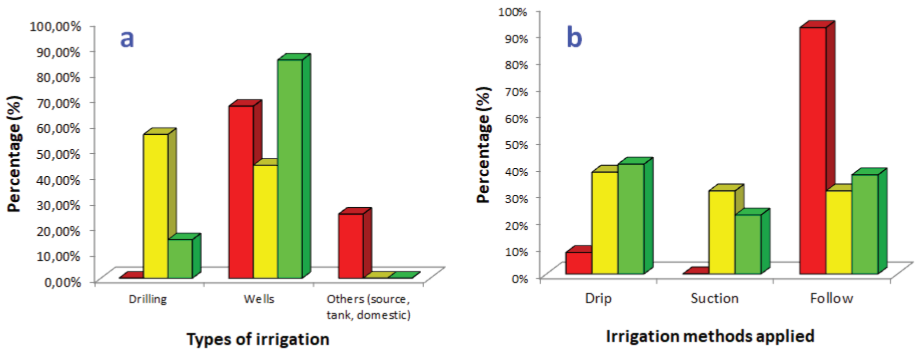

Figure 3. Irrigation practised in the studied oases
(a. types applied, b. methods applied)

Figure 4. Water sources in the studied oases
(a. source, b. well, c. accumulation basin)

Table 4. Fertilization mode in the studied oases

Oasis	Béni-Abbès	Tabelbala	Ouled Khoudir
Organic manure	100%	100%	100%
Mineral fertilization	70%	0	30%

3.3. Soil improvement

All farmers surveyed use organic manure to fertilize their plots, once a year and with ploughing. Only 30% of them, in Ouled Khoudir, use chemical fertilizer supplements such as urea and ammonium nitrates (*Figure 6*).

Organic manure has many agronomic, environmental, and qualitative advantages over chemical fertilizers, which explains its widespread use by the farmers surveyed [16, 19].

Figure 5. Fertilization and soil improvement (a. organic manure, b. fertilization method with ploughing)

3.4. Characterization and evaluation of agro-biodiversity in oasis production systems

The oases of the Béni-Abbès region are traditional agrosystems, made up of an association of three plant strata: date palms, fruit trees, and market gardening and fodder crops.

3.4.1. Date palm (Phoenix dactylifera L.)

The oases of Béni-Abbès bring together almost 17 varieties of date palm [14]. The diversity of cultivated palms is reflected in varieties of early, late, dry, or soft dates. The most dominant date palm cultivars in the oases are: *Cherka*, *Machret*, *Ghars*, *Rdemtirno*, *Faggous*, as well as a few *Dhokkar* trees. The total number of date palms counted in the prospected plots is approximately 896 trees (*Table 5* and *Figure 6*). In Ouled Khoudir, the abundance of date palm is notable, with approximately 1,748 trees. The most popular varieties are *Degla*, *Hamira*, *Tinacer*, *Hartane*, and *Cheikh*, as well as other less profitable varieties and *Dhokkar*. As for in Béni-Abbès, *Degla, Hamira*, *Tinacer*, and *Hartane* largely dominate in terms of frequency (*Table 6*). In contrast, the Tabelbala oasis shows a very advanced state of degradation with only 397 date palms. The most common varieties are *Faggous*, *Hamira*, *Tinbata*, *Khalt*, and *Adma*, with other varieties present in low percentages and often older.

Table 5. Date palm varieties recorded and frequencies of presence in the studied oases

No.	**Oasis of Béni-Abbès**		**Oasis of Tabelbala**		**Oasis of Ouled Khoudir**	
	Varieties	*Number of date palm trees*	*Varieties*	*Number of date palm trees*	*Varieties*	*Number of date palm trees*
1)	Cherka	311	Hamira	90	Hamira	516
2)	Machret	259	Tinbata	78	Degla	615
3)	Ghars	149	Khalt	58	Tinacer	279
4)	Rdemtirno	128	Adma	35	Hartane	238
5)	Faggous	49	Faggous	136	Cheikh	100
	Total	896		397		1,748

Figure 6. Phoeniciculture in the studied oases

In traditional mixed farming systems, the date palm (*Phoenix dactylifera*) plays a key role, providing an ecological shelter that maintains a high level of biodiversity. Date palm (*P. dactylifera*) represents an important genetic heritage. It is also the main crop that contributes to the income of date palm farms. It creates a microclimate that is favourable to the development of other crops by moderating the harmful effects of strong winds and intense sunlight. Finally, it constitutes a food source for humans and their herds, as well as a source of materials for crafts, construction, and energy production [22–25]. The date palm is the only species naturally adapted to this environment and its very hostile climate.

Date palm plays a major ecological role as a structuring species of the ecosystem, but it has a secondary economic role. However, it constitutes an important genetic heritage and represents the main crop in the oasis, ensuring a source of income for oasis farmers compared to other crops [24, 26–28].

3.4.2. Biodiversity of fruit species

Fruit tree growing ranks second in the oasis system. It is also of great interest to farmers due to its low water requirements, fruit production, and the income it generates. The farmers surveyed in the oases of the Béni-Abbès region attach great importance to the conservation of local varieties of certain tree species such as vine, fig tree, apricot tree, peach tree, and olive tree. At the same time, they seek to diversify their production by introducing other species such as lemon and orange trees (*figures 7–8*). Their density is very low, and they are distributed irregularly in the plots. Their production is intended mainly for household consumption.

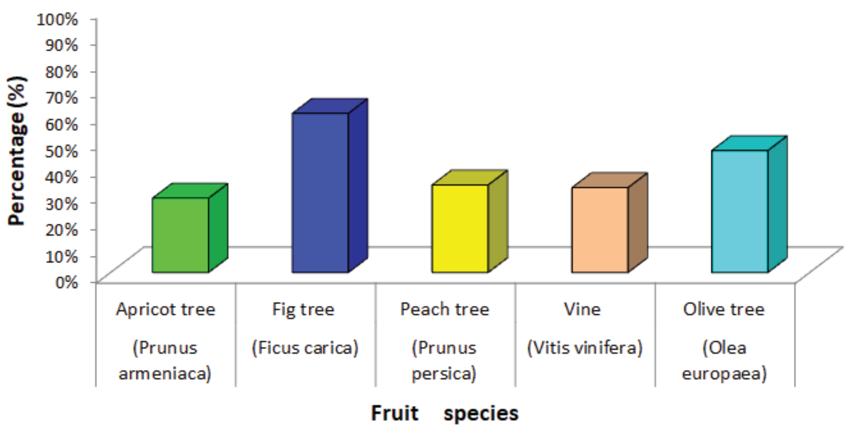

Figure 7. Fruit species in the studied oases

Fruit trees are of particular interest due to the richness of the crops and the diversity of the varieties, and they are a characteristic of traditional agrosystems. Indeed, in the oasis orchards, no less than 14 large fruit species have been identified. Among these species, we can mention:

– Fig tree represents the emblematic tree species of the oasis. It is cultivated by all farmers.

– Vine tree occupies second place in terms of varietal richness.

– The olive tree takes an increasingly important place in the oases of the study area because farmers resort to planting vines in the new extensions in order to support olive cultivation to ensure an annual income.

– Apricot cultivation has shown significant varietal richness despite the small areas.

Figure 8. Fruit species (a. lemon tree, b. peach tree, c. olive tree)

The production of peach, lemon, and orange trees is generally limited to family consumption and is of no economic interest to farmers. In general, the diversity of fruit species is very important. The three emblematic species of the Mediterranean, the olive tree, the fig tree, and the vine, are well represented there [15].

3.4.3. Biodiversity of herbaceous crops (cereals and fodder)

This level is composed of market garden crops, fodder crops, and industrial crops. These crops are grown relatively intensively, with several species being able to succeed each other in the same plot during the year. The cultivated species are very diverse, and several local varieties are still maintained by farmers.

Cereal cultivation is practised by all farmers in the oases studied. It is conducted semi-intensively, with the possibility of several successive species to be cultivated in the same plot throughout the year. The cereal species cultivated are very diverse, including soft wheat, durum wheat, barley, and maize, all local varieties being supported by the farmers (*Table 6* and *Figure 9*).

Table 6. Main cereal and fodder crops in the studied oases

Oasis		**Béni-Abbès**	**Tabelbala**	**Ouled Khoudir**
Cereals	*Soft wheat*	0	100%	93%
	Durum wheat	100%	0	100%
	Barley	83%	88%	33%
	Corn	25%	0	0
Forage crops	*Barley*	83%	88%	88%
	Oat	67%	25%	30%
	Alfalfa	25%	19%	41%
	Millet	67%	88%	48%
	Corn	25%	0	33%
	Sorghum	42%	62%	44%

Fodder crops in relation to the breeding of sheep and goats are increasingly widespread. The feed based on oat, barley, millet, and sorghum makes the cultivation of the latter highly widespread across the oasis. Sorghum is used partly to feed the herd and also constitutes an additional source of income for farmers thanks to its sale on the weekly markets. This plant tolerates and resists salt well, as do other species that are also commonly present in the oasis such as alfalfa (*Medicago sativa*).

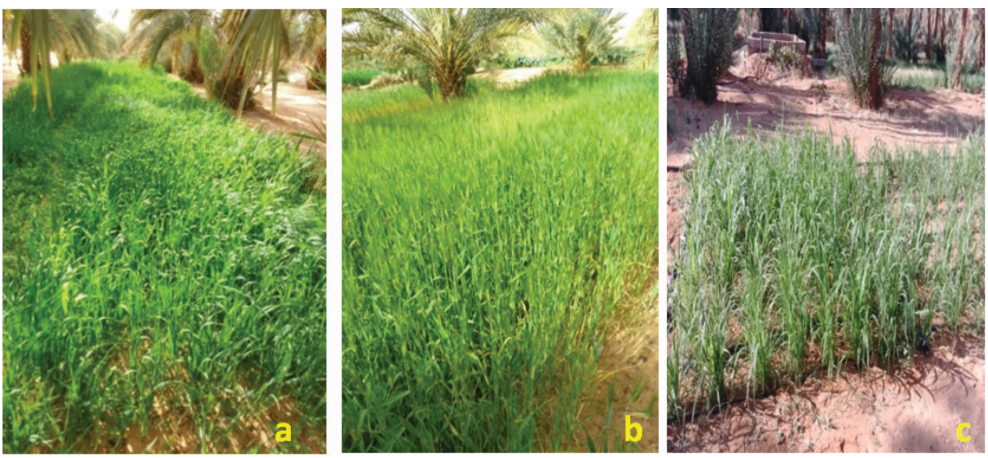

Figure 9. Cereal and fodder crops (a. durum wheat, b. barley, c. millet)

According to the work of [29] and [16], farmers give more importance to fodder crops (such as alfalfa) because of the importance of domestic livestock, often consisting of goats and sheep, in the production system.

3.4.4. Biodiversity of vegetable species

Herbaceous crops in the oases of Béni-Abbès are the most developed plant category, including vegetable crops, cereal crops, and fodder crops, as well as other crops such as condiment crops. This practice is almost universally adopted by the farmers surveyed.

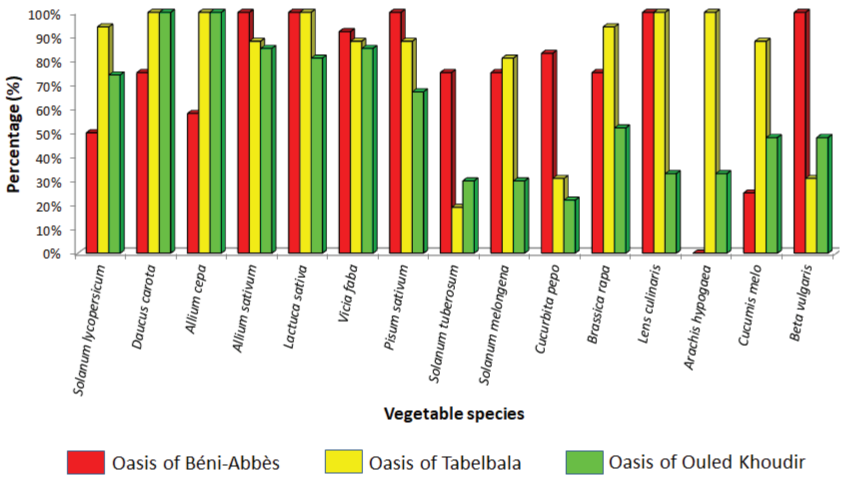

Figure 10. Market gardening crops practised at the studied oases

The cultivation of many species is recorded, with a total of 16 species listed, or an average of 11 species per plot. Market gardening is practised intensively, and the species cultivated are highly diverse, including in particular tomato, carrot, onion, garlic, lettuce, broad bean, eggplant, pumpkin, turnip, melon, and beet.

Figure 11. Market gardening crops (a. beetroot, b. potato, c. bean)

3.4.5. Biodiversity of condiment, medicinal, and aromatic species

Despite the many factors limiting the development and expansion of areas allocated to the cultivation of medicinal, condiment, and aromatic plants, they continue to resist in the oases of Béni-Abbès. In general, they are cultivated in association with other crops.

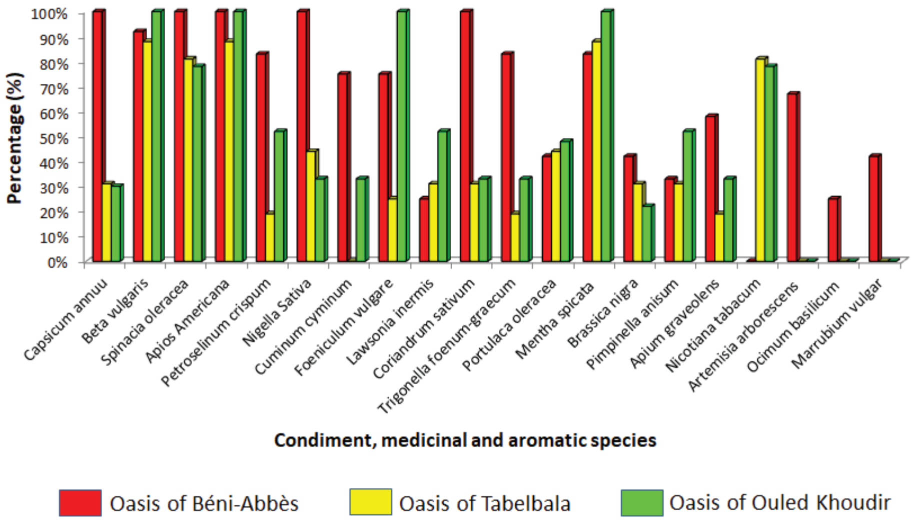

Figure 12. Farmers surveyed practising medicinal and aromatic plant cultivation

Figure 13. Medicinal and aromatic plants (a. parsley, b. wild bean, c. henna)

The main species are henna, tobacco, and pepper. As for the other species, they are currently practised by a very limited number of farmers (*figures 12–13*). There are also special cash crops such as henna and tobacco.

3.4.6. Animal biodiversity in oasis farms

The production system encountered in the study area is characterized by a diversity of production that integrates plant and animal production (Benaradj et al., 2020).

Table 7. Distribution of livestock numbers in the studied oases

Oasis	Béni-Abbès	Tabelbala	Ouled Khoudir
Sheep	116	114	244
Goats	44	49	62
Cattle	0	0	4
Poultry	26	19	72

Table 7 provides details on livestock farming in the three studied oases: Béni-Abbès, Ouled Khoudir, and Tabelbala. In Béni-Abbès, the number of sheep amounts to 116 heads, including 64 ewes, 44 goats, including 32 goats producing 13 litres of milk per day and 26 poultry. As for Ouled Khoudir, there are 244 sheep, including 131 ewes, 4 dairy cows producing 7 litres of milk per day, and 62 goats, including 42 goats producing about 18 litres of milk per day, while the number of poultry is 72. In Tabelbala, the number of sheep is 114 sheep, including 65 ewes, 49 goats, and 32 goats producing about 14 litres of milk per day, and 19 laying hens (*Figure 14*).

Figure 14. Main types of livestock farming (a. goat, b. sheep, c. poultry)

The development of fodder crops is important in all oases, especially with the integration of livestock farming into the oasis agrosystem. The importance of oasis livestock farming is partly based on the sale of animals during the Eid el-Kebir festivals.

In fact, the oasis system is essentially made up of small and medium-sized subsistence farms characterized by the use of traditional farming techniques and intensive and semi-extensive livestock farming, mainly by sheep and goats. For all the studied oases, the agrodiversity is very rich, with the presence of 50 cultivated species recorded: 4 cereal species, 5 vegetable species, 23 market garden species, 5 fodder species, and 13 fruit species. The varietal profile of the date palm tree, which is the keystone species of the oasis agroecosystem, includes several adapted cultivars (*Hamira, Faggous, Ghars Cherka, Machret, Rdemtirno, Degla, Tinacer, Hartane, Tinbata, Khalt, Adma*, etc.).

At the level of the oasis of Béni-Abbès, the crops grown are highly diverse (42 crops) and cover all the major crops: cereals (4), legumes (4), market garden crops (21), fruit crops (10), and fodder crops (3). In the oasis of Ouled Khoudir, 30 crops are recorded in all of the oasis farms: 4 cereals, 2 legumes, 13 market garden crops, 10 fruit crops, and only alfalfa as a fodder crop. Indeed, in the oasis of Tabelbala, 32 crops are recorded: cereals (3), legumes (2), market garden crops (14), fruit crops (11), and fodder crops (2).

In Algeria, most oasis production systems are essentially based on the association of four levels: phoenicicole level (date palm), arboricultural level (fruit arboriculture), herbaceous level (market garden and fodder crops), and livestock level.

According to Kradi et al. [30], this diversification of crops allows the family not only to meet its needs but also to finance (source of self-financing) certain agricultural works (ploughing, sowing, harvesting).

This set, which contains a significant genetic diversity, constitutes a harmonious and complementary system [16, 17, 19, 31–32]. This differentiation by the importance of diversity in the different strata reflects a certain specialization. This difference in diversity is due to several factors, including geographical particularities, water availability, and local knowledge [29].

According to Ater and Hmimsa [15], Boucherit et al. [33], Houssni et al. [26], Loumerem et al. [31], Salhi [17], and Aljane et al. [34], oases, like all traditional agroecosystems, are characterized by the practice of mixed farming and generally show a remarkable level of diversity, constituting a self-subsistence system to meet household needs.

In this system, various early and late cultivars are grown to cover consumption throughout the year. All production (dates, vegetables, and fruit) is intended for household consumption. Surplus production is intended for the local and regional market. Oasis agroecosystems constitute a refuge for agricultural diversity and represent a very important opportunity to conserve agrodiversity and maintain agricultural activities well adapted to local ecosystems, with a view to the sustainable development of these regions [26].

4. Conclusions

This inventory work undertaken in the three oases of the wilaya of Béni-Abbès shows a very high phytogenetic diversity of cultivated plant bioresources by identifying adapted local cultivars. This diversity reveals 44 species distributed between 15 species of market garden crops, 10 species of cereals and fodder, as well as 19 condiments, medicinal, and aromatic species. In addition to the 2,500 date palm trees dominated by cultivars (*Hamira, Faggous, Ghars Cherka, Machret, Rdemtirno, Degla, Tinacer, Hartane, Tinbata, Khalt, Adma,* etc.), there are also 5 fruit species in the oases studied, among which the fig tree stands out as the most dominant species. As for agrodiversity, it is staged in three layers and constitutes an important phytogenetic heritage in desert regions with a hyper-arid climate.

The oases and in southern Algeria represents systems based on a strong agrobiodiversity and good practices of farmers, ecological territories, and favourable habitats. These factors are economic drivers for local populations. The oases of Béni-Abbès are characterized by the dominance of the date palm with an interesting varietal diversity. The underlying crops are also very diverse. The date palm occupies a preponderant place, followed by fruit trees, market gardening, and fodder crops. The great diversity of cultivated species and their vertical distribution in three strata are: (i) the tree layer of date palm, (ii) the tree-shrub layer of various fruit trees, and (iii) the underlying herbaceous layer dominated by cereal and fodder crops. This important agrobiodiversity has a true biological potential of plant genetic resources and constitutes a challenge for the in-situ conservation and sustainable development of the studied oases.

In perspective, the safeguarding of endangered species and varieties, the reintroduction of extinct species, and the conservation of the phytogenetic heritage of the oasis are essential to preserve the adaptation and production potential of oasis cultivation systems. Therefore, it is necessary to preserve these genetic bioresources of oasis species in their natural environment, which allows maintaining their adaptive potential in the face of environmental fluctuations. This conservation can be based on the production of local seeds, the creation of specialized nurseries, the conservation plots of adapted indigenous varieties/cultivars, and their reintegration into the productive process of the oases. These advantages of phytogenetic resources deserve to be supported for a better preservation of this plant heritage, which can be integrated into sustainable development and participatory conservation actions. The preservation of the oasis space and agrobiodiversity will allow to maintain the socioeconomic and ecological interest of the region and to sustainably enhance its potential.

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Long-term effects of browsing in a beech stand

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Abstract. Our hypothesis was that the browsing damage caused by large herbivores in the seedling stage has a negative long-term impact on the quantity and quality of forest stands, trees, and timber. The data were collected in beech (*Fagus sylvatica*) stands in the Bükk Mountains, Hungary. In even-aged stands, affected by different levels of game damage after regeneration, sample and control plots were designated. The sampling method was those of quadrats within which all trees have been surveyed. Data from the areas affected by browsing and the control areas were compared. The results show that the number of trees in the forest area affected by browsing was significantly lower, and the number of forked and curved trunks was higher.

Keywords: ungulate browsing, browsing damage, shape defects, red deer, roe deer, mouflon

1. Introduction

Grazing and browsing, which is part of the lifestyle of large herbivore species, has always played a role in the structure and dynamics of natural ecosystems. Thus, when large herbivore densities in forests reach a certain threshold level, they can have a significant impact on the vegetation of their habitat [1], [2].

Large herbivores have a significant influence on forest composition and structure through their selective feeding [3], [4], which slows the growth of seedlings, prolongs their exposure to browsing, and sometimes renders them unable to regenerate [5].

Deer herbivory play a crucial role in tree regeneration as a top-down process in natural ecosystems [6]. Red deer is the first to browse the actively growing and most nutritious parts of trees, the apical shoots, and upper leaves [7]. As a result, browsing severely reduces seedling growth [4], [8].

In addition to reducing growth, browsing can also affect tree survival rates, which significantly reduces seedling density [9]. Beech is often considered a species well adapted to conditions, even under low light conditions. However, like any other tree species, it responds positively to increased light [10], and [11] suggest that regeneration growth can be adequately supported by creating an open canopy.

Náhlik et al. (2012) analysed two forest plots at the Szilvásvárad Forestry (Hungary), where in one of them a high level of wildlife damage was described [12]. The results of this study showed that fewer trees per hectare survived in the area affected by wildlife damage (3,570 ± 330) compared to the control area (4,660 ± 542). The number of seedlings in the baseline condition was not known, so no firm conclusions can be drawn, but it is a fact that in the wildlife-damaged area, there was a greater mean distance between the seedlings, which may indicate the effect of wildlife predation. Significantly lower densities of seedlings were registered in the damaged area, which may also be a consequence of wildlife predation.

Prolonged browsing can lead to a loss of habitat and species diversity, as well as the alteration of key processes such as nitrogen and carbon cycling [13].

The aim of our research was to provide evidence at the forest stand level for the hypothesis that prolonged, repeated browsing has a demonstrable negative effect on forest structure.

2. Materials and methods

For our investigation, we selected beech forest stands with similar characteristics within areas managed by the Lillafüred Forestry Directorate of Északerdő Private Joint Stock Company (*Fig. 1*).

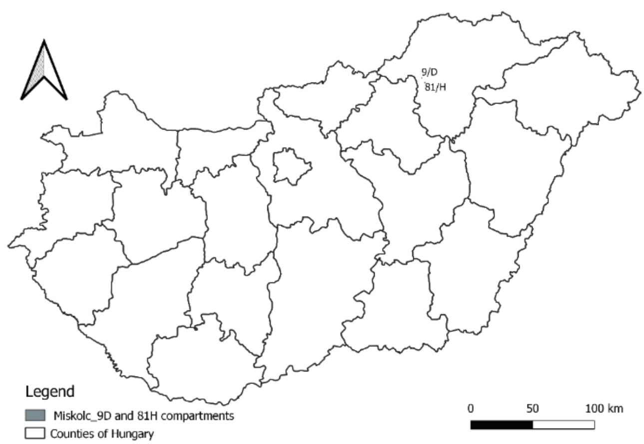

Figure 1. Location of the study area – Miskolc County, Hungary

The two forest areas were: Miskolc 81H compartment (48°05'12.39" N 20°34'12.15"; hereafter referred to as the sample area) and Miskolc 9D compartment (48°07'13.46" N 20°32'05.50"; hereafter referred to as the control area). The difference was that the sample plot was subject to wildlife damage from seedling age onwards, whereas the control plot was damage-free. The genetic soil type of both forest stands was brown soil, the topsoil thickness was deep-medium deep, and the physical soil type was loam. None of the forest stands have been affected by excess water; elevation is around 750 m above sea level, with an exposure to south-southeast (SSE) and a slope of 10-15°. The long-term target species is beech.

The sample forest compartment is located in a beech climate zone, covering an area of 4.13 hectares, of which 0.4 hectares is dead larch (*Larix decidua*) stand. The beech is of seed origin, and in addition to beech and larch, European ash (*Fraxinus excelsior*) and sycamore maple (*Acer pseudoplatanus*) are also found in the area (*Fig. 2*). First, in 1986, qualitative browsing damage occurred in 9% of the area, followed by drought in the next two years. In 1987, 2.8 ha and in 1988 0.5 ha were damaged by drought. From 1986 onwards, browsing damage was continuously recorded in the area. In 1987 and 1988, beech was replanted. In 1989, 6%, in 1992 2%, in 1993 20%, in 1994 11%, and in 1995 15% of the afforestation was damaged by wildlife. The damaging game species in all cases were red deer, roe deer, and mouflon. At that time, the control of game damage was attempted through increased damage control hunting.

Figure 2. Sample (81H) compartment

The control compartment is also in the beech climate zone, with beech of seed origin as well as the sample compartment, and has an area of 6.26 ha. Apart from beech, the species composition of the forest contains sycamore maple and European ash. The afforestation started in 1981, and there has been no significant browsing damage (*Fig. 3*).

Figure 3. Control (9D) compartment

In the studied forest stands, 7-7 sample quadrats of 10 x 10 m were randomly selected. In order to mark the sample areas, a 20 m measuring tape was used, which was marked at 10 m (side length) and 14.14 m (diagonal of the 10 x 10 m quadrat).

Within the quadrats, the height and diameter at breast height (DBH) of each tree was measured. Trunk defects (curvature and forking) below 2 m were also recorded. When determining the DBH, a simple tape measure of the circumference was used, from which the diameter of the trunk was calculated. A tree height measuring device (Suunto PM-5/1520 PC) was used to determine tree heights.

Chi-square normality tests and Kolmogorov–Smirnov goodness of fit tests were performed to check the distribution of the DBH and measured heights data among sample plots. Due to the normal distribution of data, t-tests, independent, and by-samples were used for the comparisons of mean DBH and mean heights among sample plots.

To compare the occurrence of forked and curved trunks between sample plots, 2 by 2 Chi-square tests were used.

Statistical analyses were carried out using STATISTICA version 14.0.1.25 [14] and Microsoft Excel.

3. Results and discussion

The data were recorded in the field and then evaluated in Microsoft Excel. The mean height and mean DBH per sample quadrat were calculated, and this calculation was repeated for the whole area. We also counted the number of forked and curved trees below 2 m (*tables 1–2*).

Table 1. Descriptive statistics of beech stands in sample areas

Sample plot	**Measured tree [No]**	**Mean DBH [cm]**	**Measured mean height [m]**	**Forked below 2 m [No; %]**	**Curved below 2 m [No; %]**
S1	19	14.62	16.89	7; 36.8	10; 52.6
S2	20	9.71	13.30	9; 45.0	12; 60.0
S3	14	12.66	12.85	10; 71.4	6; 42.8
S4	5	11.01	8.40	4; 80.0	3; 60.0
S5	8	13.81	9.00	4; 50.0	5; 62.5
S6	15	12.77	8.93	11; 73.3	7; 46.7
S7	15	12.51	8.80	11; 73.3	10; 66.7
Per plots	95	12.43	11.94	56; 58.9	53; 55.8
Per compartment	5,605	12.43	11.94	3,304; 58.9	3,127; 55.8

Table 2. Descriptive statistics of beech stands in control areas

Sample plot	**Measured tree [No]**	**Mean DBH [cm]**	**Measured mean height [m]**	**Forked below 2 m [No; %]**	**Curved below 2 m [No; %]**
C1	20	13.94	16.53	1; 5.0	0
C2	17	11.89	15.62	0	1; 5.9
C3	20	14.51	18.25	1; 5.0	0
C4	21	15.40	17.57	1; 4.7	0
C5	12	18.13	20.42	0	0
C6	12	20.31	20.96	1; 8.3	0
C7	13	15.85	17.92	0	0
Per plots	115	15.32	17.91	4; 3.5	1; 0.9
Per compartment	10,284	15.32	17.91	358; 3.5	89; 0.9

In the sample forest plot, 1,557 – of which 1,357 beech – trees per hectare were estimated, while in the control area 1,771 was the total number of trees per hectare, out of which 1,643 were beeches. There was also a difference in mean tree height and DBH between the two forest compartments (*Table 3*, *Fig. 4*).

Table 3. T-test results of DBH and measured height comparisons between sample and control area

Variable	Mean sample	Mean control	t-value	df	p
DBH [cm]	12,43568	15,32191	-3,5151	208	0,000540
Measured height [m]	11,93684	17,91000	-10,3053	208	0,000000

For the DBH, lower averages were observed in the sample (wildlife-damaged) area, with a significant difference ($p < 0.001$). A similar significant difference was observed for heights, the mean height in the damaged area being almost 6 meters lower than in the control area ($p < 0.001$).

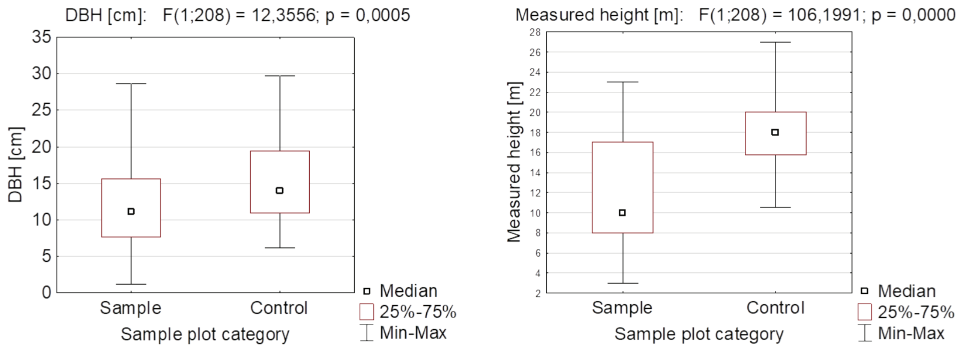

Figure 4. Boxplot by sample plot category for DBH and measured heights

Our results suggest that the browsing damage caused by large herbivores has a stronger impact on the increase in height than on the evolution of diameter at breast height.

The number of forked trees below 2 m differed significantly between the two forest plots ($\chi^2 = 78.43$, df = 1; $p < 0.001$). In the sample plot, 58.95% of the trees were forked compared to 3.48% in the control plot. In the sample area, 55.79% of the trees showed a curvature below 2 m. However, this shape defect occurred with a frequency of only 0.9% in the control area. This difference between the sample plot categories was also significant ($\chi2 = 82.15$, df = 1; $p < 0.001$).

4. Conclusions

Our study suggests that prolonged, repeated annual browsing has a negative effect on tree growth. Due to the effect over several years, some trees develop into "bonsai" trees with denser foliage on the lateral branches [15]. A smaller effect is assumed for the diameter at breast height. The damaged forest stand had a higher proportion of forked trees, which is probably a consequence of continuous browsing. Trunk defects resulting from browsing may also affect tree growth and survival [16].

The long-term impact of large herbivores' browsing depends on several factors. The most important factor is the time of browsing, but it also depends on the tree species, the growing site, and the intensity [12]. Čermák et al. (2009) found that an increase in the proportion of beech and a decrease in the proportion of species preferred over beech (e.g. maple, ash, rowan) resulted in the more intensive browsing of the latter, leading to disappearance from the stand species composition [8].

In our study, there was a difference in the number of trees per hectare between the two areas, which could also be caused by seedling mortality due to browsing. Harmer (2001) also investigated the regeneration of beech using simulated wildlife browsing treatments [17]. Wildlife browsing was simulated by clipping new shoots that were longer than 1 cm. The study showed that pruning significantly reduced seedling survival.

Results must be evaluated in the light of the fact that only two forest compartments were surveyed and that the damaged area was subject to significant and recurrent damage. The findings can be refined by increasing the number of surveyed trees and including areas with different levels of damage (in terms of timescale and intensity). The selection and designation of additional forest compartments as sample plots has started, and the surveys will be carried out in the following years, using the above-described method.

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Maize production in Central and Eastern Europe – Perspectives and challenges

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Abstract. Maize production in Central and Eastern Europe has seen significant growth over the past decades, driven by favourable climate conditions and improved agricultural practices. However, the region faces numerous challenges, including increasing climate variability, pests, and diseases, which threaten both yield and crop quality. The adoption of modern agricultural technologies and the development of drought-resistant maize varieties are seen as key strategies to enhance productivity. Integrating sustainable farming practices and addressing market fluctuations are crucial for ensuring long-term growth supplemented by integrated plant protection.

Keywords: maize production, diseases, pests, cotton bollworm, corn leaf aphid, aflatoxins

1. Maize production in recent years in the EU, Romania, and Hungary

Corn (*Zea mays* L.) belongs to the order *Poales*, the family *Poaceae*, and the genus *Zea* [1]. The global average yield has tripled since the 1960s. While in 1961, the yield was around 2 tons per hectare, today this has increased to approximately 6 tons per hectare worldwide. The growth rate of production has followed the same trend, as over the course of nearly 60 years, production has increased from 200 million tons to nearly 1.2 billion tons today [1].

The USA is one of the largest and most important corn-producing countries in the world, with a cultivated area of around 33 million hectares. Within the EU, Hungary and Romania are also among the more significant corn-producing countries [2]. EU production had been mostly stable until 2014, after which a decline has been observed. Contributing factors include population growth [3], global warming [4], drought [5], and the emergence of new pests and pathogens [6].

In Hungary, the area dedicated to corn cultivation fluctuated between 778,000 and 906,000 hectares from 2022 to 2024. While the average corn yield in 2020 was approximately 8.5 million tons, by 2024, the production had decreased to just 5.8 million tons, primarily due to drought conditions. In Romania, the dynamics of corn production showed the following trends: the cultivated area remained above 2 million hectares, but while 8.5 million tons of corn were harvested in 2023, a decline was observed in 2024, with production reaching only 7.8 million tons. This decline is notable in comparison to the record year of 2018, when production peaked at 18.6 million tons [2], [7].

The European Union's MARS (Monitoring Agricultural Resources) agricultural monitoring system has notably revised downward its projections for Romania's corn production in 2024, primarily as a result of the severe drought conditions affecting southeastern Europe. Romania, which had previously been a major competitor with France for the title of the EU's largest corn producer, has experienced a significant reduction in its production forecasts.

According to MARS, the EU's average corn yield is now estimated to be 7.03 tons per hectare, a decrease from the July estimate of 7.24 tons per hectare, reflecting a 6% decline compared to the previous year's levels. In Romania, the impact of the drought has been particularly pronounced, prompting MARS to lower the country's corn yield estimate to 3.83 tons per hectare, down from the 4.08 tons per hectare projected in July 2024. This adjustment represents an 18% reduction relative to the previous year's yield [8].

Similar reductions in corn yield forecasts have been observed in other countries in the region, including Hungary, where the estimated yield has been revised to 6.46 tons per hectare, representing a 21% decrease compared to 2023. MARS attributes these substantial declines primarily to the extreme heat experienced in Romania, with temperatures across much of the country averaging 2.0 to 3.5°C above historical norms. The period from 1 July to 17 August 2024 has been recorded as the hottest in Romania's history, further exacerbating the adverse effects on crop yields [8].

2. Most important pests, diseases, and weeds

2.1. Pests

Frit fly – *Oscinella frit* (Linnaeus, 1758)
Corn root aphid – *Tetraneura ulmi* (Linnaeus, 1758)
Corn weevil – *Tanymecus dilaticollis* (Gyllenhal, 1834)
Sharp-tailed weevil – *Tanymecus palliates* (Fabricius, 1787)

Western corn rootworm – *Diabrotica virgifera virgifera* (LeConte, 1868)
European corn borer – *Ostrinia nubilalis* (Hübner, 1796)
Turnip moth – *Agrotis segetum* (Denis & Schiffermüller, 1775)
Cotton bollworm – *Helicoverpa armigera* (Hübner, 1808)
Aphids – *Aphididae* (Latreille, 1802) [9].

2.2. Diseases

Corn chlorotic mottle – *Sugarcane mosaic virus* (SCMV)
Maize stripe mosaic virus – *Maize dwarf mosaic virus* (MDMV)
Corn bacterial wilt – *Pantoea stewartii* ssp. *stewartia* (Smith, 1898)
Corn downy mildew – *Sclerophthora macrospora* (Thirum., C. G. Shaw & Naras., 1953)
Corn smut – *Ustilago maydis* (Corda, 1842)
Corn rust – *Puccinia sorghi* (Schwein, 1832)
Corn fusariosis – *Fusarium spp.* (Link, 1809)
Corn nigrospora dry rot – *Nigrospora oryzae* (Berk. & Broome, Petch, 1924)
Corn Kabatiella eye spot – *Kabatiella zeae* (Narita & Y. Hirats, 1959) [9].

2.3. Weeds

Hairy crabgrass – *Digitaria sanguinalis* (L.) Scop.
Barnyard grass – *Echinochloa crus-galli* (L.)
Couch grass – *Elymus repens* (L.) Gould
Green foxtail – *Setaria viridis* (L.) Beauv.
Johnsongrass – *Sorghum halepense* (L.) Pers.
Redroot pigweed – *Amaranthus retroflexus* (L.)
Common ragweed – *Ambrosia artemisiifolia* (L.)
Creeping thistle – *Cirsium arvense* (L.) Scop.
Common chickweed – *Stellaria media* (L.) Vill.
Field bindweed – *Convulvulus arvensis* (L.)
Common purslane – *Portulaca oleraceae* (L.) [10].

3. Challenges concerning new pests and diseases

3.1. Corn leaf aphid (Rhopalosiphum maidis)

Aphids (*Aphidoidea*) are phloem-feeding insects belonging to the class *Insecta* and the order *Hemiptera*. Their life cycle in temperate regions is predominantly synchronized. With the onset of bud break and rising temperatures, aphid colonies begin to emerge. The plant sap consumed by aphids is typically unbalanced in composition. It is rich in sugars but deficient in certain inorganic salts and essential amino acids required for their growth. To mitigate this imbalance, aphids excrete honeydew, while the necessary amino acids are obtained with the assistance of endosymbiotic bacteria living in mutualistic symbiosis with them [11].

The corn leaf aphid (*Rhopalosiphum maidis*) feeds on a range of host plants, including corn, sorghum, sugarcane, and other cereal crops [12]. Aphid colonies typically colonize the abaxial surfaces of leaves, although they may also be found on inflorescences. Initially restricted to Mediterranean regions, this aphid species has since spread throughout Europe [13].

Figure 1. Corn leaf aphid (*Rhopalosiphum maidis*) colony on maize

Due to their rapid asexual reproduction, these pests have become global threats, resulting in annual crop losses amounting to billions of US dollars [14]. Many of these pest species have developed resistance to a broad spectrum of synthetic pesticides, leading to escalating challenges in their management. With climate change contributing to global warming, one potential avenue for controlling these pests may involve exploiting heat stress as a control mechanism [15].

To cope with heat stress, aphids have developed various physiological and behavioural adaptations. Besides this, bacterial symbionts play a crucial role in enhancing the heat stress tolerance observed in aphids. The primary symbiont, *Buchnera aphidicola* has been shown to contribute to the synthesis of heat shock proteins, which aid in the aphids' ability to withstand elevated temperatures [16].

In addition to *Buchnera aphidicola*, aphids are associated with secondary, so-called facultative endosymbionts, including species from the genera *Serattia*, *Wolbachia*, *Rickettsia*, and *Hamiltonella*. Some studies have demonstrated that these bacteria can assist aphids in their adaptation by providing protection against heat stress, as well as defending them from parasitoid wasp attacks, among other benefits [17], [18], [19], [20].

3.2. Cotton bollworm (Helicoverpa armigera) and aflatoxins

The Heliothinae (Lepidoptera: Noctuidae) is a cosmopolitan subfamily of noctuid moths, consisting of over 400 species. *Helicoverpa armigera*, the old world bollworm, has been reported across Asia, Africa, Europe, and Australia [21]. The moths typically oviposit on maize silks, and the larvae feed on the kernels [22]. Concerns have been raised regarding integrated pest management and insect resistance management due to its biological and behavioural traits, as well as its rapid adaptation to chemical control measures [23].

Helicoverpa armigera is typically capable of completing its life cycle within a temperature range of 17.5–32.5 °C [24]. Both temperature and sowing time play a significant role in determining the extent of larval damage in crops, with lower infestation rates observed in early sowing periods [25]. Severe infestations can damage the chlorophyll tissues of leaves, leading to necrosis. Certain crops, such as soybean and tomato, are particularly vulnerable, as early infestations of *H. armigera* often affect the reproductive stages, hindering pod formation and significantly reducing seed yield [26].

Figure 2. Cotton bollworm (*Helicoverpa armigera*) damage on maize [27]

The damage caused by the cotton bollworm usually affects the corn cob. Due to extensive feeding at the tip of the cob, the kernels are damaged, and the moist, hard-to-dry frass that accumulates creates ideal conditions for pathogens to infect the cob. Since the damage can occur in a hidden way under the protection of the husk leaves, controlling the pest is difficult. Feeding at the tip of the cob leads to toxin formation, which threatens the quality of the crop and, indirectly, poses a significant risk to human health.

Aflatoxins are a group of mycotoxins, with aflatoxin B1 being the most studied and considered the most dangerous. The most detailed regulations have been developed for aflatoxin B1, caused by *Aspergillus flavus* fungi [28]. The main concern for human health is that aflatoxins cause poisoning. Several studies have linked aflatoxins to liver cancer. Aflatoxins are toxic even in small amounts; they damage the liver, can cause cancer, and harm the genetic material of cells and the immune system. In large amounts, they can cause acute poisoning, which can lead to severe liver failure and even death [29]. Acute aflatoxin poisoning is the most common in developing countries, where the climate favours *Aspergillus* species and toxin production.

Climate change is expected to considerably alter the patterns of fungal and mycotoxin contamination, with aflatoxin contamination in maize emerging as the primary mycotoxin concern in Europe [30]. *Aspergillus flavus*, the principal producer of aflatoxins, is commonly associated with a broad range of plant species, with aflatoxin production being most prevalent in crops that have higher oil content (maize, nuts, etc.). The distribution and proliferation of fungi in soil are influenced by a variety of factors, including geographical location, soil composition, climatic conditions, crop rotation practices, and pest dynamics [31]. Notably, higher fungal populations are typically observed in soils rich in organic matter and essential nutrients such as nitrates, phosphates, and potassium [32].

Analysis of maize samples from various growing regions in Hungary revealed that nearly two-thirds of the samples were contaminated with *Aspergillus flavus*, with approximately 20% of these also capable of producing aflatoxin [33]. In Romania, over 90% of the maize samples were contaminated by at least one mycotoxin. Specifically, around 30% of the samples were contaminated with aflatoxin B1 (AFB1), and in 20% of these cases, the toxin concentration exceeded the maximum levels permitted by European Union regulations [34].

4. Possible challenges and perspectives

Future maize production is expected to be increasingly constrained by environmental factors, including climate change, water scarcity, and land degradation. Given the significant scale of the maize economy, it is critical and urgent to explore strategies for climate change mitigation and adaptation, addressing both biotic stresses, such as pests and diseases, and abiotic stresses, including heat and drought [35].

Maize production is confronted with a range of agronomic challenges that affect both its yield and long-term sustainability. A major concern is the impact of climate change, which poses a threat to agricultural productivity through unpredictable weather patterns and an increased prevalence of pests and diseases [36]. Economic and market factors further complicate maize production. Economic challenges are exacerbated by limited access to education and training, which hinders the adoption of improved agricultural practices. Additionally, political instability and insufficient policy support exacerbate these issues by disrupting supply chains and restricting investment in agricultural research and infrastructure [37].

To enhance maize yields under variable climate conditions, practices such as optimizing sowing windows and selecting climate-adapted cultivars can be highly effective. However, the intensive use of land for maize cultivation often leads to habitat loss and reduced biodiversity. Moreover, the monocultural nature of maize farming diminishes ecosystem resilience, making crops more susceptible to pests and diseases. Sustainable agricultural practices, such as crop rotation and agroforestry, can help mitigate these negative impacts by promoting biodiversity and enhancing ecosystem services [38–37].

Adaptation strategies, including the adjustment of sowing dates and the development of climate-resilient maize varieties, are crucial for minimizing the adverse effects of climate change on maize production. Implementing these strategies will help ensure the stability and availability of maize, thereby contributing to global food security [35].

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