EDITOR
Iqra Saddique

CLIMATE AND CROP SUSTAINABILITY

FRUIT CULTIVATION, ENVIRONMENTAL STRESSES AND RURAL DYNAMICS

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AUTHORS

Lec. Umar Obafemi SALISU
Hicham ZITOUN
Adil LAAZIZ
Rajae BELKHOU
Abdelouahed HAJJAJI
Ameur ZAGHOUANI
Amina HAMMADI
Chaima CHETIOUI
Soumia FADHLAOUI
Mohamed Rami BERBACHE
Ayoub HADJEB
Kawther BOUREZZANE
Dimeji Rotimi SONDE

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PREFACE

North Africa, with its Mediterranean climate and rich soil, is an ideal region for fruit cultivation. This book focuses on the current state of apple and date palm cultivation in Morocco and Algeria, addressing phytosanitary issues and exploring opportunities for sustainable development.

The chapters in this book delve into the specific challenges facing these industries, from pest management and disease control to the impact of climate change and human migration patterns. By examining these issues through a regional lens, the authors provide valuable insights into the complexities of agricultural production in North Africa.

This comprehensive work is a valuable resource for researchers, agricultural experts, and policymakers in these fields. It offers a detailed understanding of the current state of apple and date palm cultivation in Morocco and Algeria, as well as the broader implications of climate change on agricultural practices and rural livelihoods in the region.

Editorial Team
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Türkiye

CHAPTER 1
APPLE CULTIVATION IN MOROCCO: CURRENT STATE AND PHYTOSANITARY ISSUES

[1]Hicham ZITOUN
[2]Adil LAAZIZ
[3]Rajae BELKHOU
[4]Abdelouahed HAJJAJI

[1]Laboratory of Biotechnology, Environment, Agrifood and Health, Faculty of Sciences Dhar El Mahraz, Sidi Mohamed Ben Abdellah University, hicham.zitoun@usmba.ac.ma, ORCID ID: 0009-0004-4839-2856
[2]Laboratory of Biotechnology, Environment, Agrifood and Health, Faculty of Sciences Dhar El Mahraz, Sidi Mohamed Ben Abdellah University
[3]Laboratory of Biotechnology, Environment, Agrifood and Health, Faculty of Sciences Dhar El Mahraz, Sidi Mohamed Ben Abdellah University
[4]Laboratory of Biotechnology, Environment, Agrifood and Health, Faculty of Sciences Dhar El Mahraz, Sidi Mohamed Ben Abdellah University, Biotechnology and Sustainable Development of Natural Resources Unit, Polydisciplinary Faculty of Béni Mellal, Sultan Moulay Slimane University

INTRODUCTION

Apple production in Morocco has significantly contributed to rural employment and economic development. The Green Morocco Plan (PMV) has promoted apple cultivation, improving living conditions in rural communities (Goldberg, 2022). According to the FAO, at the national level, apple production reached 860348.52 tons in 2023, with an estimated value of 406,086 million US dollars. This production covered 51,971 hectares with an average yield of 18.30 tons per hectare. This places apple production in Morocco 17th in the world and third in Africa, behind South Africa and Egypt. However, exports of Moroccan apples were limited to 241.67 tons, representing only 0.028% of national production. Consequently, the majority of apple production is geared towards the domestic market. In contrast, imports reached a weight of 6994.16 tons, with a value exceeding 49.34 million US dollars (FAOstat, 2025). The most important apple-producing regions in Morocco are located in the high and medium altitudes in the High and Middle Atlas, where climatic and edaphic conditions are favourable for the cultivation of apple trees. However, the sector faces considerable challenges, such as pests, fungal diseases, and the extensive use of pesticides, leading to resistance issues and environmental concerns (Moinina et al., 2018; Goldberg, 2022; Kara et al., 2025).

Although more than 400 species of pests threaten apple trees worldwide, most of these herbivorous species do not cause significant damage to crop. However, with increasing globalization, some of these pests are becoming more common, causing problems for apple growers around the world, which has led to a decline in apple yield and quality (Ismailov et al., 2023). In addition to these pests, apple trees are also susceptible to various fungal diseases (Wang et al., 2021). Therefore, apple disease control in Morocco is expensive because this crop requires many pesticide sprays(Moinina et al., 2018 ; Farahy et al., 2021). These challenges highlight the need for improved pest and disease management strategies in apple production. Integrated pest management (IPM) approaches that combine biological, cultural, and chemical methods could help reduce pesticide dependence. Moreover, enhancing farmer awareness and adopting resistant apple varieties may contribute to more sustainable and cost-effective apple cultivation in Morocco.

1. HISTOIRE DU POMMIER (MALUS DOMESTICA BORKH.)

The domesticated apple, scientifically known as Malus × domestica Borkh., belonging to the Rosaceae family, is the main fruit crop in temperate regions of the world, including the northern part of the Mediterranean countries (Colpo et al., 2024). The last decade has seen considerable progress in reconstructing the history of the apple tree, thanks to the increasing availability of genetic, phenotypic and archaeobotanical data for both wild and cultivated species of the genus Malus (Cornille et al., 2014). These data suggest that the cultivated apple tree was mainly domesticated about 4000 to 10,000 years ago from Malus sieversii in the Tian Shan Mountains, Kazakhstan, located in Central Asia (Cornille et al., 2014). It was then introduced to Western Europe along the Silk Road, allowing the hybridization and introgression of wild apple species from different regions, including Siberia, the Caucasus and Europe (Brown, 2012; Cornille et al., 2014). This ancient trade route, which connected Asia, Europe, and Africa, played a vital role in spreading various crops, including apples, across these regions (Cornille et al., 2012). The introduction of grafting techniques facilitated the fixation and propagation of superior genotypes from open pollination (fortuitous seedlings), causing a real revolution in the history of apple cultivation (Cornille et al., 2019). Humans then maintained and propagated these hybrids through cloning and grafting, giving rise to the modern apple (Cornille et al., 2024).

2. NOMENCLATURE OF APPLE TREES

The apple tree is part of the order Rosales, the Rosaceae family, the subfamily Maloideae, and the genus Malus (Robinson et al., 2001). The genus Malus includes at least 20 to 30 different species, most of which are domestic cultivars resulting from interspecific hybridization due to self-incompatibility(Ibanez & Dandekar, 2007). In several years, the name Malus domestica Borkh. was retained to designate the domestic apple tree, replacing M. pumila Mill., a name that is historically and globally more widely used, as well as several other older names (Applequist, 2024).

2.1 Botanical Description of Apple Trees

Cultivated apple trees (Malus domestica) are characterized by several distinct characteristics. They usually reach a height of between 2 and 5 m, depending on the rootstock and planting system. Apple twigs can bear vegetative and flower buds. Vegetative buds promote the development of new shoots, while flower buds transform into flowers and ultimately into fruits (Bretaudeau, 1978; Milyaev et al., 2021). Apple trees have medium vigor, which can be influenced by environmental conditions and rootstock selection. The tree is branched with a single trunk and a widely spreading canopy. Young stems and branches are slightly tomentose, and older branches become hairless (Voronkov et al., 2019; Wei et al., 2025).

The apple tree is a monoecious species with hermaphrodite flowers. The reproductive structures consist of corymbs with a central flower (at the origin of the king fruit), which flowers first, and 4 to 6 lateral flowers, which flower in a temporal sequence, giving rise to the small lateral fruits (Costa & Botton, 2022) . The flowers can be pink and consist of five sepals, five petals, a multicarpellary inferior ovary (epigynous) and up to twenty stamens. After fertilization, the ovary and the accessory tissues (hypanthium) become a fleshy “pome” type of false fruit (Pereira-Lorenzo et al., 2009).

3. GLOBAL LEADERS IN APPLE PRODUCTION

The apple is one of the most produced fruits in the world after bananas and citrus fruits (Figure 1). In 2023, more than 97 million tons (Mt) of apples were produced worldwide, they were the third most produced fruit, behind bananas (FAOstat, 2025). Apple production is widespread across temperate regions, with China, the United States, and Poland being the top producers. The fruit is valued not only for its taste but also for its nutritional benefits, including vitamins, fiber, and antioxidants. Global demand for apples continues to rise, driven by both fresh consumption and processing industries such as juice and cider production.

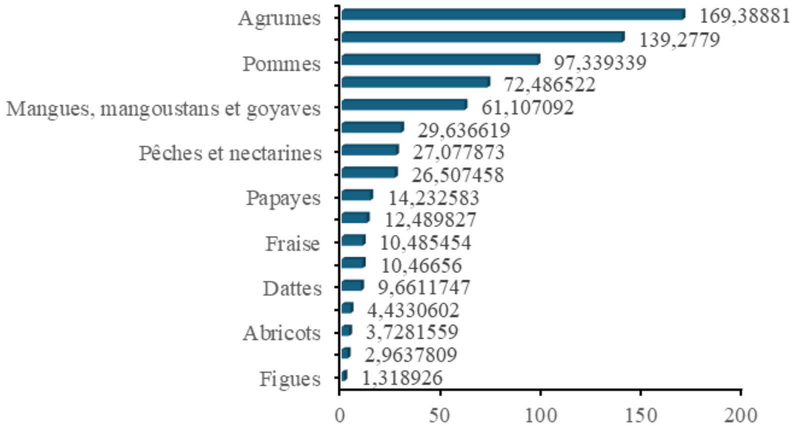

Figure 1. World production of major fruits in 2023 (FAOstat, 2025) (watermelons are excluded from the ranking).

According to data published by FAO (2025), global apple production is dominated by a small number of countries (Table 2). China accounts for 50.53% of global production, with a cultivated area representing 43.23% of the global total. However, the average yield is moderate (24.84 t/ha), and it is significantly lower than that of other major producing countries. In contrast, countries such as Chile, the United States, and South Africa, which achieve impressive yields of 50.88, 42.85, and 42.61 tonnes per hectare, respectively, by cultivating relatively small areas. These impressive feats have been made possible by the implementation of advanced farming techniques that emphasize mechanization, precision irrigation, rigorous pest control, and the use of high-performing cultivars. In contrast, countries such as Chile, the United States and South Africa produce significantly more apples. For example, Chile has yields of 50.88 t/ha thanks to advanced techniques such as wind turbines and heaters to control frost and shade nets to reduce sunburn.

In this context, Morocco is ranked 17th in the world, contributing 0.88% to global production and occupying 1.02% of the world's land. The average yield is 18.30 t/ha, which is still lower than the global average of 21.25 t/ha. This highlights the limitations of productivity in this area (Blanke & Yuri, 2020).

The United States and South Africa also achieved high yields of 42.85 t/ha and 42.61 t/ha, respectively, thanks to high-density orchards, advanced mechanization, and efficient irrigation systems (Lopuch et al., 2011; Garming et al., 2015; Dzikiti et al., 2017). (Percentages are calculated in relation to the total area and production of the world.)

Table 1. Apple production, area and yield in the world's main producing countries in 2023 (FAOstat, 2025)

Rank	Country	Production (tonnes)	Share in world production	Surface areas (ha)	Surface areas (ha)
1	China	49601700	50,53%	1996632	24,84
2	United States	5151680	5,25%	120233	42,85
3	Turkey	4602517	4,69%	167437	27,49
4	Poland	3892700	3,97%	150000	25,95
5	India	2876000	2,93%	304000	9,46
6	Italy	2267750	2,31%	54080	41,93
7	Iran	2177336,96	2,22%	106345	20,47
8	Russian Fed.	2083191,29	2,12%	201388	10,34
9	France	1894440	1,93%	53800	35,21
10	Chile	1475949,64	1,50%	29006	50,88
11	Uzbekistan	1385872,23	1,41%	120507	11,50
12	South Africa	1198897,39	1,22%	28134	42,61
13	Brazil	1183794	1,21%	33358	35,49
14	Ukraine	1172750	1,19%	75600	15,51
15	Germany	941210	0,96%	33110	28,43
16	Egypt	892140,48	0,91%	34804	25,63
17	Morocco	860348,52	0,88%	47009	18,30
	World	98153872,3	100%	4618285	21,25

4. THE EVOLUTION OF APPLE CULTIVATION IN MOROCCO

The apple tree (Malus domestica) is a major crop in Morocco. The first apple plantations in the country probably date back to the 1920s, using Spanish varieties that were adapted to low-cold-weather needs (ONCA, 2014).

Apple cultivation predominantly occurs in regions characterized by mid to high altitudes of the High and Middle Atlas Mountains, where climatic conditions such as cold winters are particularly suitable for this crop (Zguigal et al., 2006 ; ONCA, 2014). These regions comprise Fez-Meknes, Midelt, Beni Mellal-Khenifra, Haouz-Marrakech, and Ouarzazate (Nabyl et al., 2020). However, apple cultivation is mainly concentrated in the regions of Drâa-Tafilalet and Fez-Meknes, which represent 39% and 28% of the national cultivated area, respectively (Assouguem et al., 2024). This crop currently occupies about a quarter of the country's fruit rosaceae area and benefits from a dynamic market, a diversified varietal offer and a dynamic profession (Nabyl et al., 2020).

According to Table 4, between 1985 and 1995, despite a relatively low productivity (from 7.75 to 9.09 tonnes per hectare), the area under cultivation increased remarkably, from 9000 to 26,600 hectares. This growth has allowed Morocco to significantly increase its contribution to global apple production, increasing its share from 0.31% to 0.63%. From 1995 to 2010, the Moroccan share remained relatively stable, hovering around 0.5 to 0.6%, while the area increased slightly (from 26,600 to 27,314 ha). However, it was above all the improvement in yield that marked this period, rising from 11.65 t/ha to 16.29 t/ha. In recent years, the apple sector in Morocco has undergone rapid evolution thanks to the subsidies granted by the State to investors and the efforts made within the framework of the solidarity projects of the Green Morocco Plan (PMV) for the period 2008-2020 and Green Generation 2020-2030 (MAPMDREF, 2022). Indeed, between 2010 and 2023, Morocco's contribution to global production increased significantly, from 0.62% to 0.88%. The increase was due to an increase in production from 444 861 tonnes to 860 348.5 tonnes, as well as an increase in the area under cultivation from 27 314 hectares to 47 009 hectares. Thus, apple production is moving from simple local consumption to export activity thanks to investments in production and storage technologies. These investments are partly made by the PMV (El Yaacoubi et al., 2020). However, apples only represent 0.028% of national production. Their exports are mainly oriented towards the French and Senegalese markets, so most of the domestic production is destined for the domestic market (Bouichou et al., 2024; FAOstat, 2025).

Apple products are numerous and varied, including juices and vinegar. However, apple processing remains low or non-existent in Morocco (Bouichou et al., 2024).

Table 4. Evolution of apple productivity, surface area and yield in Morocco from 1985 to 2023 (FAOstat, 2025).

Year	**Morocco**			**Share of production in the world**
	Surface (h)	**Production (t)**	**Yield (t/ha)**	
2023	47009	860348,5	18,30	0,88%
2020	51871	778866,5	15,02	0,86%
2015	45207	674153,3	14,91	0,82%
2010	27314	444861	16,29	0,62%
2005	25600	308500	12,05	0,50%
2000	27800	300005	10,79	0,51%
1995	26600	309800	11,65	0,63%
1990	21000	221000	10,52	0,54%
1985	9000	120000	13,33	0,31%

5. POLLINATION OF APPLE TREES

The reproduction of the apple (Malus x domestica) is known for its complexity, as the pollination of the apple tree is mainly by cross-pollination; however, some cultivars are self-pollinating. Most apple cultivars exhibit a system of gametophytes self-incompatibility; others are semi-compatible, or even completely self-compatible. The honeybee is the primary pollinator of the apple tree. Other effective pollinators include Hymenoptera, Diptera, and Coleoptera. Wind does not seem to be an effective mechanism for pollination. Environmental conditions such as temperature, rain, and wind speed have a negative impact on pollination (Ramírez & Davenport, 2013). To ensure a sufficient and stable fruit yield in commercial orchards, it is typical to plant pollinator trees. These can be ornamental apple trees or various apple cultivars, with a density of 5 to 10% (Sheick et al., 2020). However, the cultivar used as a pollen donor must meet several criteria. Firstly, it must bloom simultaneously with the recipient cultivar.

Secondly, the quality of its pollen must meet specific requirements, such as its ability to survive, grow, germinate and multiply, as well as its ability to form functional pollen tubes (Dafni & Firmage, 2000; Crespo-Martínez et al., 2023). However, several factors, including the cultivar, geographical location, number of cold units accumulated, and climatic conditions, affect the apple tree's flowering and fruit production (Francescatto et al., 2016).

5.1 Apple Rootstock

In contemporary apple tree cultivation, apple trees are mainly made up of a scion (desired apple variety) grafted onto a rootstock (root system). This grafting technique is a widely used practice for asexual propagation of fruit trees due to its effectiveness in maintaining the genetic purity of the apple variety, improving productivity, adapting scion cultivars to adverse environmental conditions, and developing insect pest resistance traits, bacteria and fungal diseases (Habibi et al., 2022; Warschefsky et al., 2016).

About 80 years ago, most apple trees in commercial orchards around the world were propagated on seedling rootstocks. However, they had significant genetic variability, which led to heterogeneity in tree growth and fruit production. In the early 20th century, the classification, evaluation and multiplication of dwarf rootstocks allowed for their importance in the production of apple trees. This was due to the control of tree growth, increased yields, and ensured the economic viability of the orchard (Marini & Fazio, 2018; Luz et al., 2022). Indeed, the use of dwarf rootstocks has revolutionized apple production, which has moved from traditional systems based on largely planted trees at the density of 70 to 100 trees/ha to more intensive systems using smaller trees at the density of 1000 to 6000 trees/ha (Robinson, 2003, 2007).

Rootstocks affect several aspects of apple production, such as the size of the tree, the anchorage of the tree, the strength of the union between the scion and the rootstock, fruit set, potential fruit load, fruit quality, overall yield per hectare, ripening period, fruit retention capacity, and the age at which trees start to produce fruit (Lewandowski et al., 2014 ; Xiaosheng et al., 2024).

In addition, the rootstock determines several characteristics of the tree, such as its resistance to biotic stresses such as fungal diseases like scab and Phytophthora, and insect attacks like woolly aphids, and its tolerance to abiotic stresses such as drought, excess water, spring frost and winter cold (Robinson, 2007).

In Morocco, arboriculturists often place more importance on the choice of variety than on that of rootstock (Oukabli & Lahlou, 2005). Most Moroccan orchards are planted on the semi-dwarf MM 106 rootstock, which is moderate in vigor and well suited to deep, rich soils. However, their sensitivity to drought and Phytophthora (crown rot) limits their use. In recent years, other rootstocks, such as Pajam 1 Lancep, Pajam 2 Cepiland, M 9 NAKB and M 9 EMLA, have attracted a lot of interest due to their dwarfing effect and rapid fruiting (Oukabli, 2006) Therefore, trees on vigorous rootstocks such as MM.111 performed well in the hot and semi-arid climate (Oukabli & Lahlou, 2005). Moreover, some rootstocks from Cornell Geneva (USA) have demonstrated resistance to fire blight (Erwinia amylovora), Phytophthora root rot, and woolly apple adelgid (Eriosoma lanigerum) (Auvil et al., 2011; Marini et al., 2014; Fazio et al., 2015). In addition, the selection of apple grafts is based on a balanced approach aimed at obtaining high quality fruit and high resistance to diseases and pests (Gregori et al., 2017).

6. VARIETIES OF APPLE TREES GROWN IN MOROCCO

The development of new apple cultivars is usually based on several key criteria, including flavor, aesthetics, commercial qualities, disease resistance and, more recently, environmental sustainability(Kumar et al., 2014). The production of these cultivars involves a complex process of hybridization between distinct species, resulting in allopolyploids. They are propagated asexually, mainly by grafting, to preserve the specific characteristics of the selected cultivars (Brown, 2012; Li et al., 2017; F. Yang & Li, 2019). However, this process requires particularly long selection and marketing cycles (Luby & Bedford, 201). Despite its high genetic diversity, commercial production is based on fewer than 40 cultivars, including dominant varieties such as “Golden Delicious”, “Fuji”, “Gala” and “Granny Smith” (Morariu et al., 2025).

Nevertheless, there are four varieties that dominate global production, Golden Delicious, Gala, Red Delicious and Idared, together accounting for 48% of global production. Of these, Golden Delicious leads with a production of 2.546 million tons, followed by Gala with 1.331 million tons) and Idared with a production of 1.111 million tons (Marconi et al., 2018). However, in Morocco, production is mainly based on a few commercial varieties, with a dominance of the Golden Delicious and Starking Delicious varieties, which account for more than half of Moroccan production (Khachtib et al., 2022).

7. THE MAIN PESTS AND DISEASES OF APPLE TREES IN MOROCCO

Although more than 400 species of pests threaten apple trees worldwide, most of these herbivorous species do not cause significant damage to crops. However, with increasing globalization, some of these pests are becoming more common, causing problems for apple growers around the world and leading to lower yields as well as decreased apple quality (Ismailov et al., 2023). Some of the main insect pests affecting apple trees worldwide and in Morocco include codling moth (C. pomonella), green apple aphid (Aphis pomi De Geer), woolly aphid (Eriosoma lanigerum), grey aphid (Dysaphis plantaginea), red mites (Panonychus ulmi Koch) and twospotted spider mites (Tetranychus urticae Koch) (Khan et al., 2018; Moinina et al., 2018; Bangels et al., 2021; Biswas & Thakur, 2021; Erdogan et al., 2023). In addition, San Jose scale (Quadraspidiotus perniciosus Comstock) and leaf miner (Leucoptera malifoliella and Lyonetia clerkella) are also common problems (Khan et al., 2018; Ismailov et al., 2023). In addition to these pests, apple trees are also susceptible to various fungal diseases (Wang et al., 2021). Among these diseases the most common are scab (Venturia inaequalis), powdery mildew (Podosphaera leucotricha), crown rot (Phytophthora spp) (Musacchi & Serra, 2018; Grígel et al., 2019) and Monilinia spp., fungi that cause moniliosis in apple trees (Malandrakis et al., 2013).

8. THE MOST COMMON PESTS OF APPLE TREES

The codling moth (Cydia pomonella) is one of the most harmful pests that affects the production of apples worldwide, but also pears and nuts, causing economic losses of more than 62 billion dollars worldwide every year (Pszczolkowski, 2023). It probably originated in Eurasia, and then spread throughout the world, facilitated by the intensification of international trade and the development of apple cultivation (Welter, 2009; Meurisse et al., 2019). In Morocco, this pest is also considered one of the most important pests reducing the quality and quantity of crops produced (Salma El Iraqui & Hmimina, 2016). Codling moth infestations are not evenly distributed in apple orchards. Studies have shown that the distribution of larvae and damage can vary considerably within the same tree. For example, the first generation of larvae tends to attack fruit on the south sides more. This trend is likely due to microclimatic conditions such as sunshine and wind direction. In addition, the central part of the canopy often has higher infestation rates than the top or base (Stoeckli et al., 2008; Mahi et al., 2021).

The adult codling moth is a butterfly with a wingspan of about 18 mm, with an ashy colouration with dark brown wingtips (Pajač et al., 2011). This species is multivoltine, which means that it can produce several generations per year. Generations generally increase in regions with warmer climates (Beşleagă et al., 2013; S. El Iraqui & Hmimina, 2016). Its ability to adapt to various climatic conditions, including the high temperatures encountered in Morocco, allows it to complete up to three generations per year. However, when temperatures are particularly high at the beginning of the season, a fourth generation may appear. Thus, the overlapping generations, highly dependent on environmental factors such as temperature, photoperiod and food availability, makes the control of this pest particularly tricky (S. El Iraqui & Hmimina, 2016). This complexity of the life cycle requires integrated management strategies adapted to local conditions. However, the longevity of adults decreases significantly with increasing temperatures, from an average of 22.5 days at a constant temperature of 15, 17, 19 and 21 ± 1°C to only 11.7 days in conditions of fluctuating temperatures between 14.4 and 37.5°C.

In addition, the number of eggs laid can vary greatly depending on environmental conditions and the time of year. At fluctuating temperatures, the mean number of eggs per female was 92.6 for spring moths and 121.2 for summer moths. In addition, butterflies mate and lay few eggs at temperatures below 15°C or above 27°C (Blomefield & Giliomee, 2011).

Codling moths of the first generation mainly lay their eggs on the leaves near the young fruits. In particular, they favor the underside of the leaves covered in trichomes. This surface ensures better adhesion than the smooth upper surface. This preference appears to be related to microclimate conditions, including humidity, as well as the additional protection provided by the bottom surface of the leaf(Al Bitar et al., 2012; Wei et al., 2015). In addition, codling moth females, attracted to ripe fruit, find in the fruit a suitable environment for egg laying and subsequent larval development (Wenninger & Landolt, 2011).

Codling moth eggs are small, spherical eggs about 1 mm in diameter, initially white and translucent when laid. As they develop, they become milky, then develop a red ring in the center with black spots, indicating the presence of a developing larva (Blomefield & Giliomee, 2009; Mansour, 2019). The frequency of larval entry into immature apples differed by apple variety, with entry rates of 72% for Golden Delicious, 64% for Red Delicious, and 46% for Granny Smith, highlighting an influence of varieties on larval infestation (Wang et al., 2016).

The larvae feed on the fruit, causing significant damage, which is why they are considered major pests in apple orchards (Witzgall et al., 2012; Ju et al., 2023). The longevity of adults varies according to temperature. Summer moths live for about 11.7 days at temperatures ranging from 14.4°C to 37.5°C (Blomefield & Giliomee, 2011). The codling moth spends the winter as a late-stage larva encased in a cocoon, in a state of hibernation. These larvae typically seek out microhabitats such as the layer of fallen leaves at the tree's base or fissures in the bark (Rozsypal et al., 2013). The damage caused by codling moth larvae can lead to premature fruit drop and significant economic losses for growers. Effective management strategies include monitoring adult moth populations with pheromone traps and timely application of biological or chemical controls.

8.1 Aphids

Aphids are major pests of apple trees worldwide and exhibit high phenotypic plasticity. The most common species include the green apple aphid (Aphis pomi), the woolly apple aphid (Eriosoma lanigerum), and the pink apple aphid (Dysaphis plantaginea). Aphids are small insects with soft bodies (<7 mm) that feed by sucking plant sap. They can be winged (winged) or non-wingless (wingless). They usually live in colonies on the underside of leaves or tender terminal shoots. In addition, males are often absent or rare in some generations (Le trionnaire et al., 2013; Singh & Singh, 2021). Their economic impact is considerable, causing yield losses, leaf curl and drop, as well as stunted growth, and facilitating the transmission of plant pathogen viruses (Loxdale et al., 2020; Benzina et al., 2023).

Aphids have annual life cycles largely determined by the photoperiod. They have a succession of asexual (viviparous) generations in spring and summer, and a single sexual generation (oviparous) in autumn (Lin et al., 2022; Yan et al., 2020).

During favorable seasons characterized by long days, aphid populations consist exclusively of parthenogenetic females called virginiparous. During favorable seasons characterized by long days, aphid populations consist exclusively of parthenogenetic females called virginiparous. This mode of reproduction allows for rapid growth of the aphid population, as the embryos develop directly in the mother without going through the egg stage. This leads to an exponential spread of these insects. Aphids perceive the shortening of the photoperiod and cooler temperatures in autumn as a signal announcing the harsh season. This leads to a change in their reproductive mode, giving rise to sexual forms (oviparous females and males) that mate and lay eggs in diapause, resistant to winter (Barberà et al., 2019; Yan et al., 2020; Lü et al., 2024).

8.2 Green Apple Aphid (Aphis Pomi)

This species feeds on the succulent tissues of apple trees, causing various adverse effects such as leaf curl, stunted growth, tip deformity, and sooty mold development. It can also act as a vector for plant viruses (Stoeckli et al., 2008; Erdogan et al., 2023), which aggravates its impact on apple production.

The population density of green aphid varies depending on the apple cultivar and environmental conditions. For example, the Kofi cultivar in Iraq showed the greatest susceptibility to green aphids, while the Al-Rahbi cultivar was more resistant (Ahmed & Al-Khazraji, 2024). Several natural predators have been identified as effective in controlling green apple aphid populations, including hoverfly larvae (Episyrphus balteatus, Eristalis tenax, Eristalis interrupted and Sphaerophoria scripta) and lady beetles (e.g. Coelophora saucia, Cheilomenes sexmaculata) (Khan et al., 2016; Kumari, 2019; Kumari et al., 2024).

8.3 Grey Apple Aphid (Dysaphis Plantaginea)

Dysaphis plantaginea (Passerini) (Homoptera: Aphididae), named Pink Aphid, this pest mainly affects the development of apple trees and branches, causing the curling and deformation of leaves and fruit. This can have serious consequences on the marketing of apples (Stewart-Jones et al., 2008; Jacobsen et al., 2022). Even small numbers of aphids can exceed the economic threshold for damage, requiring effective pest management strategies (Blommers et al., 2004). Infestations can lead to significant yield losses, with studies showing that up to 80% of apple trees can sustain fruit damage in severe infestations (Howard et al., 2024). Aphids' feeding causes distorted growth of leaves and shoots, misshapen and stunted fruits, and the deposition of honeydew on healthy fruits. Infestations are difficult to detect at bud break, when the eggs hatch. However, once the apple tree has bloomed (late April to late May), colonies can quickly grow in size and number and severely damage the trees by midsummer (Brown & Mathews, 2008; Cockfield et al., 2011). Some apple varieties, such as 'GoldRush' and 'Galarina', show resistance to D. plantaginea by having fewer typical leaf curls and a lower abundance of aphids. Conversely, varieties such as 'Jonafree' and 'Redfree' are very susceptible to aphids. In addition, some cultivars such as 'Fuji' and 'Granny Smith' harbour higher numbers of aphids (Miñarro & Dapena, 2008; Alhmedi et al., 2022).

8.4 Apple Woolly Adelgid (Eriosoma Lanigerum)

The woolly apple aphid, Eriosoma lanigerum, is native to eastern North America. It is a major pest that affects apple trees worldwide. It threatens the survival of apple trees by infesting shoots and roots, reducing apple production. This pest forms colonies covered with white, waxy secretions on the aerial shoots and roots of apple trees, causing extensive damage (Wang et al., 2012; Stokwe & Malan, 2016), While the first instar (1st pupal stage) larvae can enter through the calyx and establish colonies inside the fruit, aphid colonies begin to appear in the spring on apple tree branches and spread throughout the summer, causing galls to form in the tissues on which they feed (Sandanayaka & Bus, 2005).

Woolly aphid has a heteroecious life cycle, alternating between asexual reproduction on apple trees (Malus × domestica) and sexual reproduction on American elm (Ulmus americana). However, outside of North America, woolly adelgids breed primarily asexually on apple trees (Godfrey et al., 2023).

The population structure includes nymphs and adults, with nymphs making up the majority (66%) of the population throughout the season. Adults (winged forms) are usually found in September and October, accounting for up to 43% of individuals in air colonies (Beers et al., 2010). Woolly adelgid overwinters primarily in root colonies, which have higher survival rates than aerial colonies (Beers et al., 2010).

Breeding apple cultivars that are resistant to woolly apple aphids is a key strategy for controlling these insects. Cultivars such as Qinguan exhibit high resistance, while Golden Delicious, Zhaojin 108 and Red General cultivars offer medium resistance (Wang et al., 2012). As for the cultivar, Red Fuji was very susceptible, while Starkrimson, Jonagold and Ralls Genet were partially resistant (Tan et al., 2021). The larvae move from the root colonies to the aerial parts of the tree and vice versa. Peaks in larval density are often higher in the lower parts of the tree, indicating migration from root colonies. Aerial colonies can be detected from late May to mid-October, with some colonies appearing as early as mid-April (Beers et al., 2010).

Since the withdrawal or restriction of the use of some broad-spectrum insecticides, E. lanigerum has become one of the most important pests in the apple-growing regions of Western Europe. Effective management relies on understanding the larval migration schedule and population dynamics of woolly aphid. Monitoring data can help predict critical response periods. Biological control using natural enemies such as the parasitoid Aphelinus mali (Hymenoptera: Aphelinidae) and the European earwig, Forficula auricularia, can help keep woolly adelgid populations below damaging levels (Beers et al., 2010; Bangels et al., 2021). Effective management of Dysaphis plantaginea in apple orchards involves a combination of chemical treatments, varietal selection and ecological strategies. The promotion of natural enemies through flower strips and other agroecological infrastructure, as well as the selection of resistant cultivars, can significantly reduce aphid populations and associated damage, thus contributing to more sustainable apple production systems.

8.5 Ants and Aphids

The pink apple aphid, Dysaphis plantaginea Passerini, and the green apple aphid, Aphis pomi De Geer, are serious pests of apple and are frequently seen together in apple orchards. Both species establish mutualistic relationships with ants (Nagy et al., 2013). The mutualistic relationships between some species of ants and aphids are well known, with their main advantages being ants protect aphid colonies from natural enemies, such as predators and parasitoids, thus increasing the survival rate of aphid colonies and aphids secrete a considerable amount of honeydew, a sugary liquid, Usually rich in carbohydrates and protein and other valuable nutrients, which is an essential food source for them (Fischer et al., 2015, 2017; Gull-E-Fareen et al., 2020). The presence of ants can stimulate the reproduction of aphids, leading to faster population growth (Xu et al., 2021). In addition, the presence of honeydew facilitates the growth of various fungi that form sooty mold. This black biofilm inhibits photosynthesis by coating the leaves, which can lead to reduced plant growth and vigor (Magyar et al., 2023).

To manage aphid populations in agricultural settings, the exclusion of ants by sticky barriers or by supplemental feeding of ants with sugar, is an effective method to support biological control of apple aphids by improving the effectiveness of their natural enemies (Nagy et al., 2013; Nagy et al., 2015).

8.6 Mites (Tetranychidae)

Spider mites of the Tetranychidae family are small plant-eating organisms, usually measuring between 0.20 and 0.90 cm. This family includes a significant number of species, with estimates ranging from 1,275 to 1,345 different species (Migeon, 2015). These mites are highly polyphagous and are capable of infesting a wide variety of plant species. Specifically, they can infest up to 4,000 distinct plant species, making them a major concern for agricultural and ornamental crops (Ochoa et al., 2011; Razuvaeva et al., 2023). These tiny herbivores use their stylets to pierce the mesophyll cells of the leaves and inject saliva, after which they suck out the cytoplasm. This results in cell death, visible as chlorotic spots sometimes accompanied by necrosis, and eventually leaf drop. In addition, it has recently been shown that mites can attenuate or even suppress plant defenses (Jonckheere et al., 2016).

8.7 The European Red Spider Mite

The European red spider mite, Panonychus ulmi (Koch, 1836) (Acari: Tetranychidae), is a polyphagous pest of various tree and fruit crops, including apple trees (Joshi et al., 2023). The damage caused by P. ulmi is mainly manifested by yellow spots on the leaves, resulting from its feeding behavior of sucking up the cellular contents of the leaves, resulting in a decrease in leaf chlorophyll. This causes leaf tanning followed by early defoliation, which can reduce the photosynthetic capacity of the tree and lead to a drop in yield (Thiel & Nauen, 2006; Raxmanov & Sulaymonova, 2023). During severe infestations, mites can colonize fruit, leading to reduced fruit size and loss of color (Thiel & Nauen, 2006; Gottwald, 2016). In addition, P. ulmi infestations can lead to changes in hormone and mineral levels that could reduce floral induction the following year (Martínez-Villar et al., 2024). The development and population dynamics of the mite are influenced by the nutritional content of the host plant.

For example, higher nitrogen levels in apple leaves can increase the fecundity and longevity of mites, exacerbating the infestation (Bhardwaj et al., 2005). The red spider mite is distinguished by its rapid development cycle, especially in summer. With a temperature of 25°C, an entire generation can be produced in about two weeks. Each female of this species has the ability to lay about 45 eggs during her breeding period (Sengonca et al., 2003; Dar et al., 2016; Kasap & Atlihan, 2021). This fecundity can vary considerably between apple varieties. At a temperature of 23°C and a humidity of 75%, the fecundity of Panonychus ulmi is higher in Golden Delicious (34.12 eggs per female) than in Fuji (27.15 eggs per female), Starkrimson Delicious (25.15 eggs per female) and Granny Smith (20.62 eggs per female) (Mohd, 2015).

In Morocco, the European red mite was observed for the first time in three apple orchards imported from Europe. Its spread has been facilitated by the expansion of apple cultivation and various dispersal factors, making it a widespread pest in most Moroccan orchards (Tixier, 2003; Vicente, 2003; Ouassat, 2019). Several studies have highlighted the influence of abiotic factors, in particular temperature and altitude, on the population dynamics of Panonychus ulmi. It has been observed that in the locality of Aït Sebaa (Fez-Meknes region), characterized by relatively high temperatures and lower altitude, the population of P. ulmi reaches particularly high levels. On the other hand, in the Midelt region (Drâa-Tafilalet), located at a higher altitude, the density of the mite remains relatively low. An intermediate situation is reported in Imouzzer-Kender (Fez-Meknes region), where population levels of P. ulmi remain moderate. These observations suggest a positive correlation between temperature and abundance of P. ulmi, and, conversely, a negative correlation between altitude and infestation by this species (Assouguem et al., 2024).

Under adverse conditions, many arthropods have the ability to enter diapause and synchronize their development and reproduction with the seasons. Diapause, or hibernation, in insects and mites is triggered by several signals, with the photoperiod being the most accurate and powerful signal (Bryon et al., 2017) . Panonychus ulmi overwinters as an egg, unlike most other mite pests. These eggs are mainly laid in late summer and early fall on the branches of apple trees, and are able to withstand harsh winter conditions (Ghazy et al., 2016).

In the spring, these eggs hatch, and the young larvae move to the new shoots in the spring and continue to multiply throughout the growing season (Ghazy et al., 2016; Koveos & Broufas, 1999)

8.8 Two-Spotted Spider Mite

Tetranychus urticae, also known as the two-spotted spider mite, is a cosmopolitan pest. In recent years, it has become one of the pests of greatest concern for apple farming, causing both quantitative and qualitative damage (Hong et al., 2021; Raxmanov & Sulaymonova, 2023). This pest feeds on the sap of leaf cells, resulting in water loss and necrosis of mesophyll cells. This causes symptoms such as whitish or yellowish speckles on the upper surface of the leaves. This diet can lead to a decrease in chlorophyll levels and changes in the behaviour of the stomata, resulting in a decrease in photosynthesis and transpiration, leading to a decrease in fruit yield and quality (Liu et al., 2016; Sonika et al., 2017; Hong et al., 2021). In addition, Tetranychus urticae is a cosmopolitan pest whose rapid rate of development allows it to form colonies of thousands of individuals in a short time. This proliferation is largely due to its mode of reproduction, which is based on arrhenotocal parthenogenesis. This means that males are born from unfertilized haploid eggs, while females are born from fertilized diploid eggs (Agut et al., 2018; Abubakar et al., 2023). Additionally, a solitary virgin female can only produce male offspring. Once mature, these males mate with the female, giving birth to bisexual offspring (Tuan et al., 2016).

The spider mite, Tetranychus urticae, goes through four active stages during its life cycle: larva, protonymph, deutonymph, adult. Cycle time at 23°C and 40–60% relative humidity is 10–12 days. Each of these mobile stages is followed by a resting phase (chrysalis) in which the moulting process is prepared (Mothes-Wagner, 1984). In addition, T. urticae, known for its great dispersal ability, can migrate from the surrounding landscapes, especially from nearby forests and orchards to apple orchards. This migration is influenced by landscape composition, with a positive correlation between forest area and the presence of T. urticae in apple orchards (Komagata et al., 2024). In winter, to survive adverse conditions, Tetranychus urticae overwinters as adult females, unlike Panonychus ulmi which hibernates as eggs.

These females stop feeding and do not lay eggs. However, a specific diet is essential after the last moult to promote the accumulation of carotenoids and facilitate the transition to a diapause stage (Bryon et al., 2013; Kawaguchi et al., 2016). Diapausing females change color from greenish yellow to bright orange due to the accumulation of keto-carotenoids, which are derived from β-carotene(Kawaguchi et al., 2016). In addition, these females undergo physiological changes. include metabolic suppression, increased stress tolerance, and the production of cryoprotectants, such as antifreeze proteins and polyols (e.g., mannitol, sorbitol), that improve cold tolerance (Khodayari et al., 2013; Bryon et al., 2017).

8.9 The San Jose Louse

The San Jose louse (Quadraspidiotus perniciosus Comst.), commonly known as San Jose mealybug, is a species native to East Asia that was accidentally introduced to countries such as the United States, Argentina, Australia, and New Zealand. This species is found in the Palearctic and Nearctic regions (Ivanov, 2024). It infests a wide variety of fruit crops, including apples, peas, and other ornamental plants (Deligeorgi et al., 2008). The San Jose louse attacks the roots, stems, leaves, and fruits of the apple tree throughout the year, sucking up sap, which can eventually lead to the death of the tree (Hix et al., 1999; Endarto & Wicaksono, 2020). The pest is highly harmful, and the risk of infestation is particularly high when netting for apple production (Ivanov, 2024).

9. APPLE REPLANT DISEASE

Apple replant disease occurs when apple trees or related species are replanted in the same location, resulting in significant growth reduction, yield loss and fruit quality. This complex disease is a global problem for apple nurseries and orchards. Its causes are not yet fully understood, and economically viable and sustainable control measures do not currently exist (Mahnkopp et al., 2018). It is a complex soil-borne disease that is a major obstacle to the profitability of fruit production. The effects of PRM include root necrosis and impaired development of absorbent hairs (Cavael et al., 2020).

It is caused by soil organisms, which stunt the growth of apple trees, decreases the yield and quality of apples, and increases susceptibility to diseases and pests. The replanting of apple trees affects the pH, nutritional value, enzymatic activity, concentration of toxic substances (e.g. phenolic compounds such as pyrogallic acid, chlorogenic acid and phlorizine) and the community of microorganisms (e.g. pathogenic fungi) of the soil, thus deteriorating its physical and chemical properties. Soil-borne pathogens, including fungi, bacteria, actinomycetes, and nematodes, are typically involved in MRP (Yang et al., 2010).

Selecting and planting disease-resistant apple varieties can provide long-term protection against common pathogens. For example, the use of rootstocks such as "CG.6210" and "CG.30" has been shown to be effective in controlling diseases related to apple replanting (Leinfelder & Merwin, 2006).

CONCLUSION

Apple growing occupies an important place in Moroccan agriculture, especially in mountainous regions where the climate is favorable for apple cultivation. However, this sector faces several phytosanitary obstacles, including fungal infections and pest infestations, which adversely affect yield and quality. Apple cultivation is often affected by fungal diseases such as apple scab (Venturia inaequalis) and downy mildew (Podosphaera leucotricha), which can reduce fruit yield and quality. Pests like the codling moth (Cydia pomonella), aphids and mites can cause damage to fruits and leaves, resulting in yield losses. To overcome these constraints, the sector must adopt integrated management strategies that combine prevention, monitoring, biological control and rational use of pesticides.

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CHAPTER 2
DATE PALM CULTIVATION IN BISKRA (ALGERIA): EVOLUTION, CLIMATIC AND BIOTIC CONSTRAINTS, AND PROSPECTS FOR SUSTAINABLE DEVELOPMENT

[1]Ameur ZAGHOUANI
[2]Amina HAMMADI
[3]Chaima CHETIOUI
[4]Soumia FADHLAOUI
[5]Mohamed Rami BERBACHE
[6]Ayoub HADJEB
[7]Kawther BOUREZZANE

[1]Laboratory of Diversity of Ecosystems and Dynamics of Agricultural Production Systems in Arid Zones (DEDSPAZA), Department of Agronomic Sciences, University of Biskra, ameur.zaghouani@univ-biskra.dz, ORCID ID: 0009-0009-4771-1938

[2]Laboratory of Improvement and Development of Plant and Animal Production, Department of Agronomic Sciences, University of Sétif 1, hammadiamina@univ-setif.dz, ORCID ID: 0009-0004-4421-1982

[3]Laboratory of Improvement and Development of Plant and Animal Production, Department of Agronomic Sciences, University of Sétif 1, chetioui_chaima@univ-setif.dz, ORCID ID: 0009-0007-9590-9581

[4]Technical Institute of Development of Saharian Agriculture (ITDAS), Biskra, soumia.fadlaoui@univ-biskra.dz

[5]Laboratory of Diversity of Ecosystems and Dynamics of Agricultural Production Systems in Arid Zones (DEDSPAZA), Department of Agronomic Sciences, University of Biskra, mohamedrami.berbache@univ-biskra.dz, ORCID ID: 0000-0003-0751-463X

[6]Laboratory of Diversity of Ecosystems and Dynamics of Agricultural Production Systems in Arid Zones (DEDSPAZA), Department of Agronomic Sciences, University of Biskra, ayoub.hadjeb@univ-biskra.dz, ORCID ID: 0000-0003-3981-5066

[7]Laboratory of Diversity of Ecosystems and Dynamics of Agricultural Production Systems in Arid Zones (DEDSPAZA), Department of Agronomic Sciences, University of Biskra, kawther.bourezzane@univ-biskra.dz

INTRODUCTION

The date palm is a thermophilic desert plant well-adapted to arid environments, with Algeria cultivating more than 18 million trees across the country (Rekis & Laiadi, 2020). Located approximately 430 km southeast of Algiers at an elevation of 88 meters above sea level, Biskra serves as a transitional zone between northern and southern Algeria and has emerged as the nation's leading producer of date palm fruits. The region is characterized by predominantly flat terrain surrounded by the Ziban mountains, with small water sources found within oases and canyons, particularly around El Kantara (Oukil et al., 2023).

Within Biskra province, the Tolga Oasis Complex stands as one of the largest oasis settlements in the Sahara Desert of North Africa, encompassing more than 1,006,600 date palm trees (Berkouk et al., 2020; S. Matallah, 2021). This complex has gained international recognition for producing high-quality Deglet Nour dates, with production reaching 1,356,202 quintals in 2017 (M. Matallah, Alkama, Teller, et al., 2021). The region experiences a hot arid climate (Köppen BWh classification) with significant seasonal temperature variations, making it well-suited for date palm cultivation while presenting unique challenges for sustainable agricultural development (M. Matallah, Alkama, Mahar, et al., 2021).

The Biskra region, located in southeastern Algeria, represents a major strategic hub for date palm cultivation, playing a predominant role in national and international date production. The date palm (Phoenix dactylifera L.) is not only a vital economic pillar for this region, providing income for farmers and numerous jobs, but it is also a fundamental component of the socio-cultural and environmental fabric of the oases (Benyagoub, 2023). The reputation of Biskra dates, particularly the Deglet Nour variety, has been established in global markets thanks to their exceptional taste qualities (Le Gal et al., 2007)). However, this essential sector faces increasing challenges related to climate variations and the persistence of biotic stresses, which directly impact fruit yield and quality. (Latifian, 2017). This report offers an in-depth analysis of the evolution of date production in Biskra, while examining in detail the impact of these environmental and biological factors on the sustainability of this emblematic crop.

Phoeniciculture represents one of the strategic agricultural sectors in Algeria, not only due to its economic weight but also because of its social, cultural, and territorial dimensions. With a production regularly exceeding one million tonnes since the 2010s, Algeria ranks among the top three global producers, boasting a unique date palm heritage consisting of over 900 varieties, including the famous Deglet Nour, renowned for its superior quality and international recognition (Benghoulam & Khaldi, 2019; FAO, 2021). The sector significantly contributes to the national economy through job creation, the revitalisation of trade, and the foreign exchange earnings generated by exports, while also playing a structuring role in the development and sustainability of oasis areas (Benziouche, 2017; Chehat, 2014). The evolution of national date production illustrates an upward dynamic: estimated at nearly 300,000 tonnes in the 1960s, it experienced rapid growth thanks to the expansion of cultivated areas, the modernisation of agricultural practices, and public policies aimed at food security and economic diversification (Bessaoud, 2019; Rural (MADR), 2020). However, this progress is not without challenges, such as dependence on a dominant variety, vulnerability to diseases like bayoud, and difficulties related to international marketing (Chao & Krueger, 2007; Daoudi, 2018). These constraints call for a sustainable strategy for enhancing and developing the sector.

In this context, the wilaya of Biskra holds a prominent position, constituting the true heart of national production. It concentrates between 40 and 45% of the total production, notably thanks to the Deglet Nour variety, which benefits from optimal agro-climatic conditions there(Benziouche, 2017; Rural (MADR), 2020). The Tolga region, in particular, is globally recognised as a terroir of excellence for the production of high-end dates, making Biskra the "date capital" of Algeria (Battesti, 2005; FAO, 2021). Beyond raw production, Biskra stands out due to the presence of packaging, processing, and export units, thereby strengthening its contribution to the competitiveness and enhancement of the sector at both national and international levels (Chehat, 2014; Daoudi, 2018). Thus, the Algerian date palm sector constitutes a major development lever, and its analysis through the case of Biskra appears particularly relevant for understanding growth dynamics, challenges, and valorisation prospects.

The objective of this chapter is to examine the evolution and strategic role of date production in Algeria, with a particular focus on the wilaya of Biskra, in order to identify the conditions and opportunities for its sustainable development.

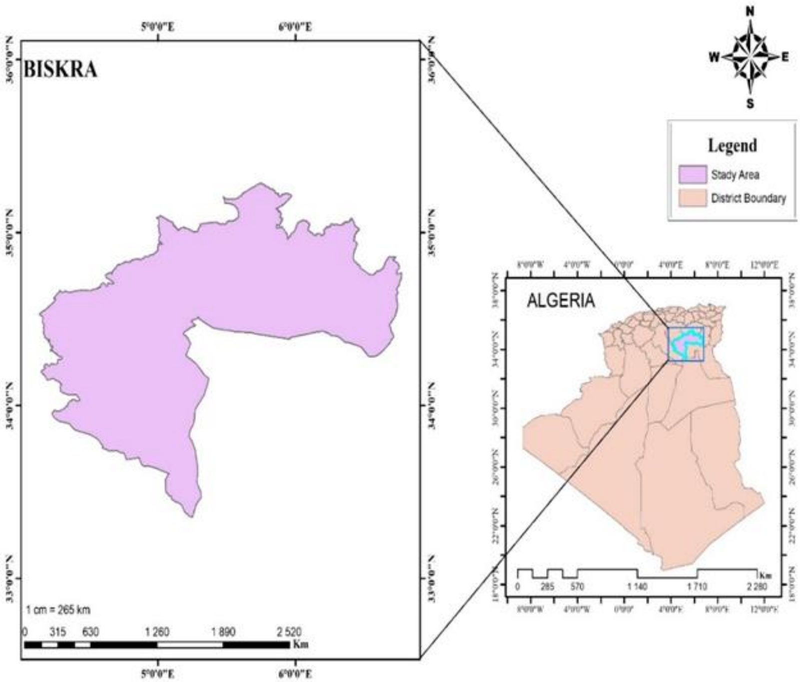

Figure 1. Geographic location of the Biskra region, Algeria

1. HISTORICAL EVOLUTION AND TRENDS IN DATE PRODUCTION IN BISKRA

The Ziban region, with Biskra at its heart, has historically been the main date production area in Algeria, accounting for a significant number of producing wilayas. (Hanane et al., 2022). During the 20th century, date palm cultivation in Biskra experienced constant expansion, resulting in an increase in cultivated areas and the number of date palms. Mihi et al., 2019. The date palm has always been the most important agricultural crop in the Algerian desert, occupying more than half of the arable land (Foufou, 2009).

A study in the oases of southeastern Ziban (Biskra) revealed that the expansion of palm groves, increasing from 2 to 4 million palm trees over the past decade, has allowed for rapid colonisation by certain bird species (Absi et al., 2015). In the wilaya of Biskra, the total number of date palms amounted to 4,121,858, of which 2,753,079 were productive in 2008 (Khedidja, s. d.). The Biskra department contributes 27% to the national date production, with 3.5 million palm trees (Sabah et al., 2023).

1.1 Production Volumes and Recent Trends

Algeria is ranked among the world's leading date producers, holding the fourth global position with 16 producing provinces. (Benyagoub, 2023). The production of the Bechar province, for example, increased from 2,446 tonnes in 2015 to 59,781.3 tonnes in 2021 (Benyagoub, 2023). Biskra is a major player, contributing a significant portion of the national production. (Hanane et al., 2022; Sabah et al., 2023). The studies conducted from 2010 to 2012 on 89 varieties of date palms in Biskra helped identify their distinctive phenotypic characteristics, highlighting a rich biodiversity in the region (Simozrag et al., 2016). Algerian date production is dominated by the Deglet Nour variety, recognised as the most well-known, but also includes soft dates and other types (Mimouni, 2023). At the national level, date production is considered strategic, and Algeria ranks as the seventh-largest exporter worldwide (ABDELMALEK, 2020). Recent trends (since 2000) show a continuous growth in production in Biskra, with a significant share of national production (Faiza, 2024).

1.2 Varietal Diversity with Emphasis on Deglet Nour

The Biskra region is home to a remarkable diversity of date varieties. The Deglet Nour is the predominant and most prized variety, particularly that of Tolga, recognised for its superior qualities and export value. (Le Gal et al., 2007). This variety has forged Biskra's reputation in international markets. (HADDOU et al., 2021a). However, other varieties are also cultivated, such as Ghars and Degla Beida, which represent a significant portion of the production. (Benyagoub, 2023).

A study on 54 cultivars in Algeria identified several varieties with good morphological and biochemical characteristics, notably Aghares, Baydh-Elkadhi, Bouarous, Bouldjib, Dguel-M'ghas, Figuigue, Horra, Mezith, Ouarglia, Sebaa-Bedraa, Tacherouint, Tafazouine, Tamsrit, Tawragha, Timjouhert, and Tindokan (Said et al., 2014). The characterisation of these varieties is essential for their identification and description. (Simozrag et al., 2016). Maintaining this genetic diversity is crucial for the resilience of date palm cultivation in the face of environmental constraints. (Debabeche et al., 2023).

1.3 Dynamics of Date Palm Cultivation and Production in Biskra (2016–2021)

Figure (02) illustrates the general trend in the total number of date palm trees during the study period. The results show a gradual increase in the number of trees, reflecting the continuous expansion of date palm cultivation in Biskra, which can be linked to land reclamation programs and the encouragement of planting high-value commercial varieties. Conversely, any stagnation or decline observed in certain years may be attributed to climatic factors (drought, hot winds) or biological constraints (pests, diseases, or aging trees).

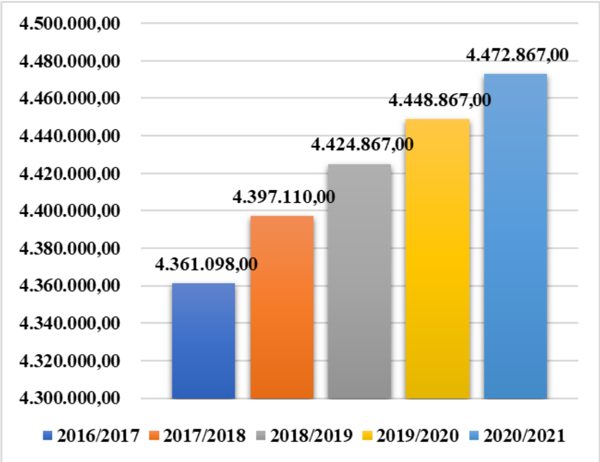

Figure 2. Temporal Evolution of the Total Number of Date Palm Trees in Biskra (2016–2021)

1.3.1 Temporal Evolution of the Productive Date Palm Population (2016–2021)

Figure (03) shows the dynamics of productive date palms compared to the total population. A remarkable increase in the number of productive trees is evident, which reflects the entry of new plantations into the fruiting stage. The gap between the total and the productive palm population represents an important reserve for future production, highlighting the role of agricultural practices (irrigation, fertilization, pruning) in accelerating the onset of production and enhancing yield.

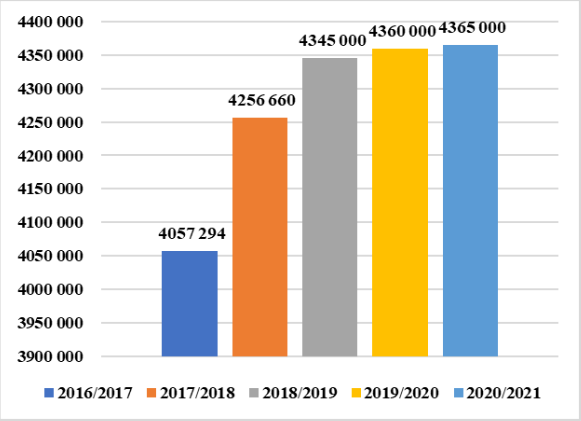

Figure 3. Temporal Evolution of the Productive Date Palm Population in Biskra (2016–2021)

1.3.2 Spatio-Temporal Trends in Date Production in Biskra (2016–2021)

Figure (04) presents the spatial and temporal distribution of date production across the municipalities of Biskra. The results reveal clear spatial variability in production, reflecting differences in environmental conditions (soil quality, water availability) and farming techniques. The temporal variation in production is associated with climatic fluctuations or the expansion of cultivated areas. These results highlight the importance of certain municipalities as key production zones compared to others with lower productivity.

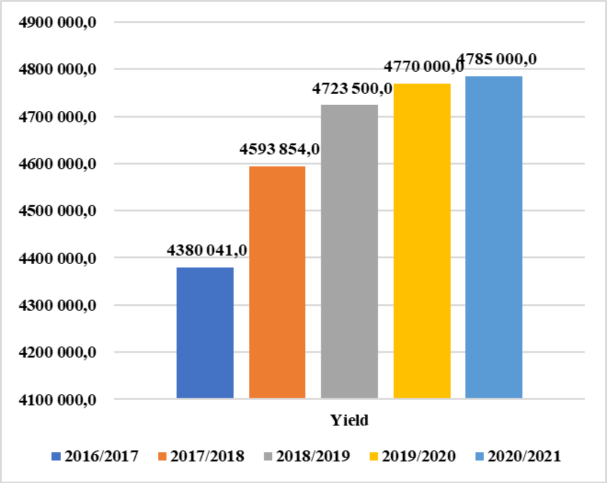

Figure 4. Spatio-Temporal Trends in Date Production across Biskra Municipalities (2016–2021)

1.3.3 Temporal Dynamics of Deglet Nour Date Palm Population (2016–2021)

Figure (05) highlights the development of the Deglet Nour variety, which is the most commercially important cultivar. The results indicate a steady increase in the number of Deglet Nour palms, reflecting farmers' preference for investing in this variety due to its high economic value and strong market demand locally and internationally. This expansion confirms the central role of Deglet Nour in strategies for developing palm cultivation in the region.

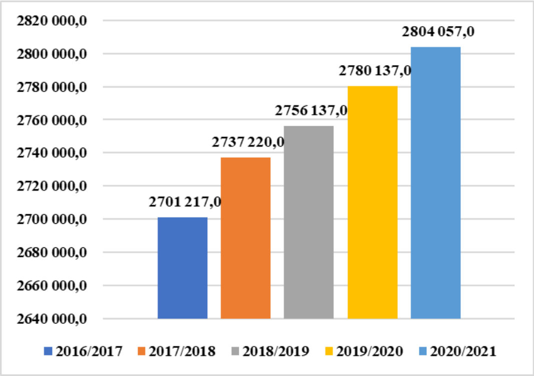

Figure 5. Temporal Dynamics of the Deglet Nour Date Palm Population in Biskra (2016–2021)

1.3.4 Evolution of Productive Deglet Nour Date Palms (2016–2021)

Figure (06) illustrates the growth of productive Deglet Nour palms during the study period. The increase in productive trees confirms the success of agricultural strategies focusing on this variety. The entry of new plantations into the fruiting stage has reinforced the position of Biskra as a leading production hub of this date variety at the national level.

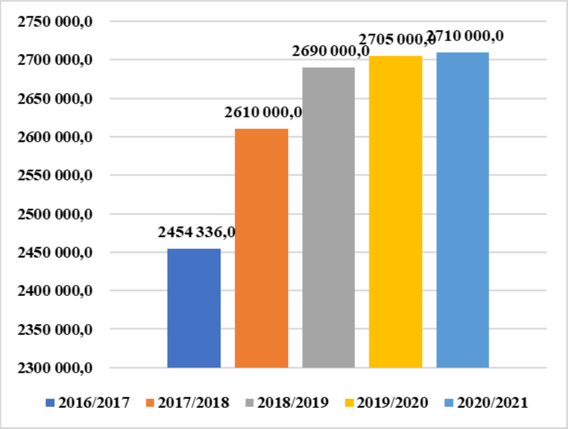

Figure 6. Evolution of Productive Deglet Nour Date Palms in Biskra (2016–2021)

1.3.5 Spatio-Temporal Trends in Deglet Nour Production in Biskra (2016–2021)

Figure (07) depicts the spatial and temporal variability in Deglet Nour production. Certain municipalities stand out for their abundant and high-quality production, confirming the existence of specialized areas for cultivating this variety. Temporal changes in production are closely linked to climatic conditions and the availability of irrigation infrastructure. These findings clearly demonstrate that Deglet Nour represents the cornerstone of the date economy in Biskra and that sustaining its production depends on the development of agricultural practices and the orientation of investments towards highly productive areas.

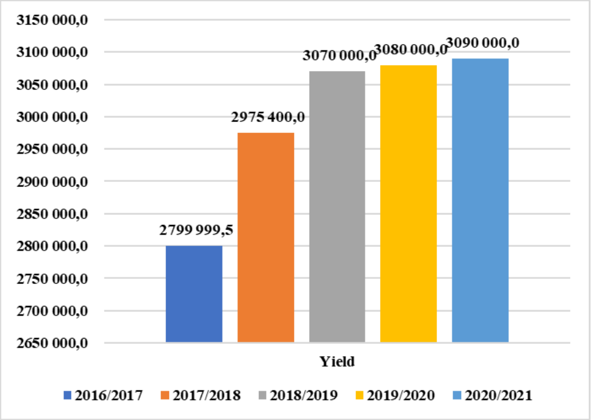

Figure 7. Spatio-Temporal Trends in Deglet Nour Date Production across Biskra Municipalities (2016–2021)

1.3.6 Evolution of Date Palm Cultivation In Biskra

Date palm farming has been conducted in the Ziban region for centuries, with agricultural systems historically defined by oasis-based use (Hemidi & Laamari, 2020). The cultivation method has significantly evolved, especially beyond traditional oases, where palm groves no longer adhere to the classical three-stage oasis system but have transitioned into mono-cropped plantations dedicated to the production of Deglet Nour dates for both domestic and export markets (Kuper et al., 2016).

The accessibility of groundwater resources has significantly propelled agricultural expansion, facilitating the establishment of new palm groves and the emergence of greenhouse horticulture since the 1980s. The swift growth resulted in Biskra becoming as Algeria's second-largest agricultural producer by 2012, representing 37% of the nation's date production (Kuper et al., 2016). This progress has presented considerable obstacles. Contemporary oasis agroecosystems are experiencing rapid degradation due to socio-economic concerns, including an ageing workforce and insufficient supply and production resources, environmental challenges such as sanitation issues and urban encroachment, and technical problems stemming from inadequate farming techniques.

A multitude of cultivators have ceased their activities, as younger farmers increasingly pursue prospects beyond oasis, resulting in a deficiency in the replacement of ageing and deceased palms in conventional groves (Faci, 2019). The sustainability of this evolution is jeopardised by significant groundwater overexploitation, with current irrigation consumption approximated at 1.2 km^3 annually—467% of the renewable groundwater resources accessible. Consequently, farmers face declining groundwater levels and are compelled to regularly deepen their tubewells to sustain production (Kuper et al., 2016).

1.3.7 Current Production and Economic Significance

Biskra has emerged as Algeria's most important date palm production region and a major agricultural hub with significant economic impact. The region achieved the distinction of being Algeria's leading producer of date palm fruits while also becoming a prominent center for greenhouse production (Oukil et al., 2023). By 2012, Biskra ranked second in Algeria in total agricultural production, generating approximately 1.24 billion euros in agricultural output—trailing only behind another Saharan region, El Oued (Kuper et al., 2016).

The scale of date production in Biskra is substantial, with the region accounting for 37% of all dates grown in Algeria as of 2012 (Kuper et al., 2016). Within Biskra province, the Tolga Oasis Complex represents one of the largest and most productive date palm settlements, containing more than 1,006,600 date palm trees (Berkouk et al., 2020)). This complex has gained international recognition for producing high-quality Deglet Nour dates, with production reaching 1,356,202 quintals in 2017 (M. Matallah, Alkama, Mahar, et al., 2021).

The economic significance extends beyond traditional date varieties, as the region cultivates eight major date palm varieties that serve as principal sources of income for local residents (Harkat et al., 2022). These include four soft date varieties (Deglet-Nour, Ghars, Itima, and Tentbouchet), three dry varieties (Degla-Baida, Haloua, and Mech-Degla), and one semi-soft variety (Arechti), with production focused on readily marketable dates for both domestic and export markets (Harkat et al., 2022; Kuper et al., 2016).

The agricultural transformation has been accompanied by diversification into greenhouse horticulture, which began in the 1980s and expanded rapidly to include almost 100,000 greenhouses covering approximately 4,000 hectares by 2010. This diversification has contributed to Biskra's broader agricultural significance, with the region also accounting for 25% of Algeria's tomato production by 2012 (Kuper et al., 2016).

2. CLIMATIC FACTORS AND THEIR IMPACTS ON THE DATE PALM

The Biskra region experiences a subtropical hot desert climate that creates substantial constraints for date palm cultivation and agricultural workers (Oukil et al., 2023). The region is characterized by hot and very dry summers with cold winters that can reach subfreezing temperatures (Hemidi & Laamari, 2020). During summer months, temperatures average around 43.5°C but often peak above 48°C, accompanied by extremely low relative humidity of just 12%. Winter conditions bring average minimum temperatures of 4°C with relative humidity reaching 89% (Oukil et al., 2023).

Precipitation remains severely limited across the region, with annual rainfall of only 138mm occurring over fewer than 31 days each year (Oukil et al., 2023). Comparative data from other date-growing regions shows Biskra receives 141mm annually, which is double that of Ghardaia (68mm) and El Oued (74mm), though still extremely limited (Mezroua et al., 2017). During critical growing periods from March to June, precipitation is particularly scarce, with some years recording as little as 5mm (Hemidi & Laamari, 2020).

These extreme climatic conditions create severe challenges for agricultural workers during the phenological cycle of date palms. Research shows that cultivators work under extreme temperatures for 5.5 months during the growing cycle, with severe discomfort occurring when temperatures reach 30°C or above. While spring periods provide more comfortable working conditions, workers experience slight to extreme discomfort during summer and fall seasons, especially between midday and 7 p.m. (M. Matallah et al., 2022).

Although date palms can tolerate air temperatures up to 50°C for short periods and low humidity conditions if adequate water is available in the subsoil, the lack of precipitation exposes trees to excessive soil salts. Water scarcity and very high temperatures represent some of the greatest obstacles for sustainable date palm cultivation in the region (Kavvadias et al., 2024).

2.1 Water Resources and Irrigation Challenges

Water resources and irrigation management represent the most pressing challenges facing date palm cultivation in the Biskra region. Current groundwater use for irrigation is estimated at 1.2 km³ per year, which represents 467% of the renewable groundwater resources available (0.26 km³/year), indicating severe overexploitation of aquifer systems. This overexploitation extends to the Continental Intercalaire aquifer, which while containing enormous reserves (91,900 km³), is non-renewable or little renewable (Kuper et al., 2016).

The consequences of this overexploitation are directly impacting agricultural operations, as farmers are confronted with decreasing groundwater tables and must frequently deepen their tubewells to maintain access to irrigation water (Kuper et al., 2016). Water scarcity, combined with very high temperatures, represents one of the greatest future obstacles for date palm cultivation in the region (Kavvadias et al., 2024).

Traditional irrigation systems have evolved significantly over time to address these challenges. Historical systems like the "Fuqaqir" method, which involves extracting groundwater through shallow wells connected by underground channels, have long sustained agriculture in desert environments. During the colonial period, some regions adopted adaptations of ancient Roman Lamasba legislation for water distribution, which proved effective due to uniform farm sizes and equal water distribution (Attia et al., 2024).

Modern irrigation challenges are compounded by climate change impacts on water resources. Notable research shows that climate change has led to mal-distribution and irregularity of precipitation, drought conditions, decreased natural recharge, and increased groundwater abstraction.

Water quality has also deteriorated, with salinity levels ranging from 2.5 to 90 g/l in southern areas—far above permissible limits for agricultural activities (Gagou et al., 2023; Hamed et al., 2018).

Despite these challenges, modernization efforts are underway to improve water resource efficiency through advanced irrigation techniques while preserving traditional methods that are part of the region's agricultural identity (Attia et al., 2024). Efficient management practices, including modern irrigation systems and enhanced soil water retention techniques, are essential for sustaining date palm cultivation and productivity in this water-scarce environment (Kavvadias et al., 2024).

2.2 Main Climatic Stresses and Their Effects

- **Several climatic stresses affect date palm cultivation in Biskra**: Drought and Water Stress: Drought is a recurring phenomenon and one of the main climatic challenges in arid regions. (Otmane et al., 2025). Date palms, although adapted, suffer from increased water stress due to decreased precipitation and intense evaporation. This stress affects the growth of palm trees and the quality of dates. (Suleman et al., 2001).
- **Salinity:** Date palm oases in the Biskra region face multiple biotic constraints that threaten their long-term sustainability. Soil salinization has emerged as one of the most pressing biological threats, caused by water resource limitations, increased salinity of irrigation water, and reduced drainage water discharge in agricultural lands (Gagou et al., 2023; Hamed et al., 2018). The lack of precipitation exposes date palm trees to excessive soil salts, creating challenging growing conditions despite the species' ability to tolerate air temperatures up to 50°C and low humidity when adequate subsoil water is available (Kavvadias et al., 2024). Salinity is a major constraint, exacerbated by the use of irrigation water with high salt content. Soil salinisation reduces the biometric characteristics of dates (length, width, weight) while increasing their total sugar content (HADDOU et al., 2021b). However, a salinity level of -0.35 to -1.97 MPa can promote the growth of certain fungi, such as C. radicicola and T. paradoxa (Suleman et al., 2001).

- **Heat Waves:** Excessive temperatures, often accompanied by low humidity levels, cause thermal stress in palm trees, which can influence their metabolism and fruit growth (Morand-Fehr & Doreau, 2001). These extreme conditions are a limiting factor for date production (Bouzelmate et al., 2025).
- **Late Frosts and Sandstorms:** Although less frequent, late frosts can damage young shoots and inflorescences. Sandstorms, frequent in the region, have a mechanical impact on palm trees and fruits (Cantat et al., 2019).

2.3 Impact on Date Yield and Quality

Climate variations have a direct impact on the yield and quality of dates in Biskra. A study in Biskra showed that 30% of the production was deteriorated in quality due to climatic factors, including the fall and decomposition of dates before harvest or their fermentation (Faci et al., 2021). Salinity, in particular, reduces the biometric characteristics of fruits (length, width, weight) while increasing their total sugar content (HADDOU et al., 2021a). Changes in thermo-hygrometric conditions can also accelerate ripening, which affects the colour, texture, and aromatic profile of the fruits (Faci et al., 2021). Biochemical and physicochemical studies have confirmed these correlations, showing that high amino acid contents are associated with a lower shelf life.

3. BIOTIC FACTORS AND THEIR EFFECTS ON DATE PALM CULTIVATION

Disease pressure represents another major biotic constraint, with Fusarium wilt (Bayoud disease) caused by Fusarium oxysporum f. sp. Albedinis being particularly problematic (Gagou et al., 2023). Recent research has identified emerging threats from new plant pathogens, including two newly discovered Alternaria species associated with leaf spot and blight symptoms that reduce both yield and quality of dates, leading to significant economic losses (Djellid et al., 2025). The biotic constraints are compounded by poor agricultural management practices and aging infrastructure within traditional oasis systems. Many palm groves now contain aged palms with high height and fragile stamina that limit cultural operations and affect production (Faci, 2019).

Date palm cultivation occurs primarily in dryland soils characterized by alkaline pH, coarse texture, low plant productivity, and minimal organic matter inputs, making trees more susceptible to disease and pest attacks (Kavvadias et al., 2024; Kroeger et al., 2021).

3.1 Main Pests

Date palm cultivation in Biskra is threatened by several major pests:

- **The white scale of the date palm (Parlatoria blanchardi)** is a major pest whose development is influenced by climatic and biotic factors. Its proliferation is limited by predators and parasitism (ACHOURA, 2013).
- **The date moth (Ectomyelois ceratoniae)** is one of the most formidable pests, threatening date production in Algeria (HADJEB, 2012; ZOUIOUECHE, 2021). It infests the fruits, depreciating their quality by crawling under the calyx (ADOUANE, 2023).
- **Thrips** have been identified in the region, posing new potential threats to production (Nouere et al., 2020).
- **The boufaroua (Oligonychus afrasiaticus)**, a yellow mite, is another significant pest of the date palm (Amel, 2021).
- **The hybrid sparrow (Passer domesticus x P. hispaniolensis)** causes losses through pecking and fruit drop.

3.2 Diseases and Pathogens

Date palms in Biskra are also susceptible to various diseases: Vascular fusariosis, or Bayoud, is a devastating disease that causes irreversible decline in date palms in Algeria and poses a serious threat to phoenicicultural heritage (DJEKIREF, 2021). Fungal diseases, such as inflorescence rot and Alternaria leaf spot, are common and can reduce yield and fruit quality (Haldhar et al., 2017). Species of fungi such as Chalara radicicola and Chalara paradoxa have been identified as opportunistic pathogens, especially in cases of water stress. (Suleman et al., 2001). Effective management of these diseases requires a combination of cultural practices, resistant cultivars, and careful monitoring of environmental conditions. Proper irrigation and soil management can help reduce the impact of opportunistic fungal pathogens.

3.3 Impact of Biotic Factors on Organoleptic and Market Quality

Biotic infestations have a direct impact on the organoleptic and commercial quality of dates. The date moth, for example, degrades the quality of the fruit by developing within it (HADJEB, 2012). Diseases and pests can lead to production losses of up to 30%. The phytosanitary condition of the Biskra palm groves reveals a heavy infestation by the date moth (34.52%) and the white scale (27.14%), both impacting the quality. The presence of these pests and diseases makes the dates less attractive for marketing and consumption (ADOUANE, 2023).

3.4 Interactions Between Climatic And Biotic Factors

Environmental conditions modulate the pressure of pests and diseases. Palms stressed by drought or salinity are more vulnerable to attacks by opportunistic pathogens. The lack of water and extreme temperatures can promote the development of necrotic lesions and the death of buds. For example, the water potential of -2.3 MPa in seedlings subjected to water stress led to more significant necrotic lesions (Suleman et al., 2001). Pest activity is also influenced by climatic factors; the date palm white scale, for example, shows population fluctuations based on oasis ecological parameters (Achoura, 2013). Host-pathogen interactions are studied in relation to the epidemiological risks of diseases like Bayoud (Djekıref, 2021).

4. AGRICULTURAL PRACTICES AND INNOVATIONS FOR SUSTAINABLE PRODUCTION

The date farmers of Biskra use a combination of traditional and modern practices to optimise yield and quality:

- **Irrigation Management:** Irrigation is essential in this arid region (Debabeche, 2021). Localised irrigation, particularly through buried drip irrigation, is adopted for efficient water use (Sabino, 2001). The frequency of irrigation is a key factor in the components of yield.
- **Fertilisation:** The fertilisation of the date palm has been little used traditionally but has become more common.

Phytosanitary practices include the management of irrigation and fertilisation.

- **Pruning:** Pruning palm trees is essential for controlling growth and the quality of dates. A good pruning promotes fruiting (Khouane, 2012).
- **Pollination:** Manual pollination is a crucial traditional practice (Boubekri, 2008). Innovations include mechanical pollinators, which offer similar yields to the traditional method but with time and safety savings. The best percentage of pollen/wheat flour is 20% for pollen dispersal (Nourani et al., 2016). The application of gibberellic acid can improve the length and reduce the acidity of dates (Khouane, 2012).

4.1 Technological and Biotechnological Innovations

The improvement of date palm tolerance to stress relies on technological innovations:

- **Plant Biotechnologies:** Micropropagation allows for the production of a large number of elite, healthy, and vigorous plants. Cryopreservation and in vitro gene banks are used for the conservation of genetic resources (Khokhar & Silva, 2017).
- **OMICS Techniques:** Molecular markers, including sex-specific markers, are useful for discriminating germplasm and identifying somaclonal variants derived from tissue cultures (Khokhar & Silva, 2017).
- **Genetic Engineering:** The genetic transformation of the date palm can be achieved through particle bombardment or Agrobacterium-based protocols (Khokhar & Silva, 2017).
- **Assisted Pollination:** The development of mechanical pollinators reduces manual labour and costs (Nourani et al., 2016). These tools contribute to the resilience of palm groves in the face of climatic and biotic challenges (Fernane & Hannachi, 2021; Masure et al., 2023). Moreover, they enhance the efficiency and consistency of pollination processes, ensuring higher fruit set and quality. Their use also supports sustainable agricultural practices by minimizing the dependence on seasonal labour availability.

4.2 Integrated Pest Management (IPM) Strategies

Integrated Pest Management (IPM) is a multidisciplinary approach combining various methods:

- **Biological Methods:** The fight against the date palm white scale, for example, relies on the study of its natural auxiliaries (S. Matallah, 2021). Biopesticides are being studied for the date moth (Latifian, 2017).
- **Cultural Methods:** Phytosanitary practices in Biskra include crop diversity, irrigation, and fertilisation methods. Abderrahmane & Omar, n.d. Water and soil fertility management are essential.
- **Chemical Methods:** The use of chemicals is an option, but the LI aims to reduce it to the necessary minimum (Hmimina, 2014).

5. SUSTAINABILITY AND QUALITY MANAGEMENT

Organic agriculture is a growing trend in Biskra, responding to a demand for healthy and environmentally friendly products (Vassy & Vincent, 2011). Organic dates are thriving in the wilaya of Biskra.

- **Economic Advantages:** Organic agriculture offers economic advantages by reducing input costs and allowing for better product valuation, often sold at higher prices (Deneuville, 2011).
- **Environmental Benefits:** It contributes to the protection of water and biodiversity by limiting the use of pesticides and chemical fertilisers (Vassy & Vincent, 2011).
- **Social Benefits:** It can strengthen farmers' autonomy and improve their working conditions (Deneuville, 2011). Quality certification is essential for the export of Biskra dates. It ensures compliance with microbiological and physico-chemical standards. Organisations like AFNOR or ISO define these standards (Isnard & Calve, 2002).

5.1 Quality Criteria and Evaluation Methods

The dates of Biskra are evaluated according to strict criteria:

- **Sugar Content and Texture:** Sugars are the predominant components of dates (Said et al., 2014). The taste quality, including sweetness and texture, is paramount (Sabino, 2001).

- **Size and Colour:** Dimensions (length, diameter, weight) and colour are important morphological indicators (Said et al., 2014).
- **Suitability for Preservation:** Conservation is crucial, with physical and physico-chemical criteria studied for several varieties (Reynes et al., 1994).

Evaluation methods include physico-chemical analyses (sugar content, acidity, % of juice, firmness), organoleptic tests, and microbiological controls (Sabino, 2001).

5.2 Public Policies and Institutional Frameworks

The date sector is considered strategic in Algeria, benefiting from public policies and support programs (Carcillo et al., 2017). Agricultural development programs aim to improve production and quality (Mimouni, 2023). Research institutions play a key role in the evaluation of cultivars and the study of date characteristics (Said et al., 2014).

5.3 Key Actors in the Date Industry

The date industry in Biskra operates through a complex and interconnected value chain. Each stakeholder plays a specific role in ensuring the production, quality control, and commercialization of dates both locally and internationally. Several actors are involved in the value chain in Biskra:

- **Producers:** They are the foundation of the sector, cultivating palm trees and harvesting dates. (Bensaadi, 2011).
- **Cooperatives:** They help with the marketing and development of organic agriculture.
- **Research Institutes:** Organisations like the National Institute for Agronomic Research (INRA) conduct studies on the diversity and quality of dates (Le Gal et al., 2007).
- **Certification Bodies:** They ensure compliance with quality standards, particularly for export (Isnard & Calve, 2002).
- **Exporters:** They are essential for the marketing of Biskra dates in international markets. Cabeza-Orcel & Moureaux, 2018.

6. CHALLENGES, OPPORTUNITIES, AND FUTURE PERSPECTIVES

Climate projections for Biskra by 2050-2100 indicate a significant increase in temperatures and a decrease in precipitation, which will intensify water stress and soil salinisation. Krim & Hassani, 2023. These changes could also increase the frequency and intensity of extreme events like heat waves and droughts. Gallic, 2017. The impact on agricultural production could be negative, particularly for yields.

6.1 Priority Areas of Scientific Research

- To strengthen the resilience of date palm cultivation, priority research areas include:
- The study and enhancement of genetic diversity to identify resistant varieties (Debabeche et al., 2023; Moussouni et al., 2017).
- The development of sustainable agronomic systems (Amrani & Senoussi, 2016). Applied research in integrated phytosanitary management, particularly against white scale (S. Matallah, 2021).
- The optimisation of water and soil management to combat drought and salinity (Debabeche, 2021).
- The integration of biotechnological advances, such as gene editing, to improve stress tolerance (Khokhar & Silva, 2017).

6.2 Scenarios for Adaptation and Sustainable Development

Adaptation scenarios involve strategies to manage water scarcity and salinisation, the selection of adapted varieties, and the development of organic agriculture (Lattre-Gasquet et al., 2017). Sustainable development is a major focus, aiming to reconcile economic growth, resource preservation, and improved social conditions (Torre, 2021). The valorisation of dates through transformation into high value-added products is an opportunity.

6.3 Opportunities for Economic and Social Development

The date industry in Biskra offers opportunities for economic development through export and product enhancement. Organic agriculture, in particular, allows for better valorisation and higher prices. The transformation of dates into derivative products can create new sources of income. Date palm cultivation supports employment and the maintenance of communities in oases.

6.4 Prospects for Sustainable Development

The potential for sustainable development of date palm cultivation in Biskra is contingent upon addressing the primary challenges of water scarcity and agricultural efficiency through integrated strategies that amalgamate traditional knowledge with contemporary technology. Effective management practices, such as the implementation of modern irrigation systems, the selection of cultivars optimally suited to local environmental conditions, and the enhancement of soil water and nutrient retention, are crucial for sustaining date palm cultivation and productivity in this arid environment (Kavvadias et al., 2024). These practices are increasingly vital as water scarcity, elevated temperatures, salinity, soil degradation, and disease pressures constitute the most significant future challenges for date palm cultivation (Kavvadias et al., 2024).

International collaboration has emerged as a pivotal strategy for developing sustainable agricultural systems in the region. To bolster investment and trade in a modern, sustainable horticulture sector, Algeria has partnered with the Netherlands to develop practical greenhouse systems tailored to the local harsh arid environment (Ariom et al., 2022). These adaptive greenhouse systems are based on the SmaSH (smart sustainable horticulture) concept, which optimizes greenhouse designs for specific settings, climate conditioning, climate control, substrates, and nutrition management, thereby enabling farmers to substantially increase their yields (Ariom et al., 2022).

Nevertheless, current agricultural practices continue to encounter efficiency challenges that must be addressed for long-term sustainability.

Water and land-use efficiency remain suboptimal, with issues exacerbated by low-cost water that is pumped free, low annual precipitation of less than 250mm, and intermittent greenhouse relocations to evade soil-borne diseases (Ariom et al., 2022).

The path forward necessitates the preservation of valuable traditional irrigation methods while integrating modern technologies. Efforts to modernize agricultural and irrigation systems using advanced techniques aim to enhance water resource efficiency and increase date palm productivity, while preserving traditional methods such as the "Fuqaqir" system, which are integral to the region's agricultural identity (Attia et al., 2024). Historical examples, such as adaptations of ancient Roman Lamasba legislation for water distribution, illustrate that traditional approaches can be effective when properly implemented with uniform farm management (Attia et al., 2024).

Sustainable development also encompasses maximizing the economic value of date palm cultivation through improved utilization of agricultural residues. Enhancing the beneficial uses of date palm residues could lead to sustainable and economic growth in arid areas, generating additional revenue streams while reducing waste (Kavvadias et al., 2024).

CONCLUSION

The Biskra region, a pillar of Algerian date cultivation, faces complex and interdependent challenges. The evolution of its date production, characterised by historical growth and notable varietal diversity, is now threatened by rapid climate changes and the constant pressure of biotic factors. The rise in temperatures, the decrease in rainfall, soil salinisation, and the proliferation of pests and diseases directly impact the yield and quality of dates, requiring adapted and innovative responses.

To ensure the sustainability of this emblematic crop, a holistic approach is imperative. This includes the widespread deployment of sustainable agricultural practices, such as localised irrigation and rational fertilisation, combined with the adoption of biotechnological innovations to develop more stress-resistant varieties. The integration of biological control and cultivation methods into an integrated pest management strategy is crucial to minimise the use of chemicals and preserve the ecological balance of palm groves.

At the same time, support for organic farming initiatives and quality certification offers opportunities for economic enhancement and market differentiation. Public policies, research institutes, and all stakeholders in the sector must collaborate closely to strengthen the resilience of Biskra's palm groves, thereby ensuring the quality and quantity of its date production in the face of future challenges.

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CHAPTER 3
A REVIEW OF CLIMATE CHANGE EFFECTS ON FARMER–HERDER MIGRATION CONFLICTS IN NIGERIA

[1]Dimeji Rotimi SONDE
[2]Lec. Umar Obafemi SALISU

[1]Department of Transport Management, Olabisi Onabanjo University, ORCID ID: 0000-0002-7141-664X, sondedimeji5@gmail.com
[2]Department of Transport Management, Olabisi Onabanjo University, ORCID ID: 0000-0003-1630-3420, umar.salisu@oouagoiwoye.edu.ng

INTRODUCTION

Climate change is one of the most pressing challenges of the twenty–first century, with wide-ranging consequences for the environment, livelihoods and political stability across the globe. Rising global temperatures, erratic rainfall, desertification and extreme weather events are disrupting ecosystems and undermining the security of resource-dependent populations. These challenges are particularly acute in Sub-Saharan Africa, where the majority of people depend on rain-fed agriculture and livestock for survival. With limited adaptive capacity, communities in this region face heightened risks of livelihood insecurity, violent conflict and displacement (Intergovernmental Panel on Climate Change [IPCC], 2022; World Bank, 2021). Globally, efforts to address these threats have produced encouraging results. For example, in Kenya's Turkana region, community peace committees linked to water governance initiatives have reduced tensions between farmers and herders. Ethiopia has integrated climate adaptation into rural development strategies, while Niger has restored degraded lands through the Great Green Wall Initiative, reducing competition over scarce resources. These cases demonstrate that with inclusive governance, sustainable resource management and proactive climate adaptation strategies, the cycle of resource conflict can be disrupted.

In Nigeria, the situation is particularly severe. The country's diverse ecological zones, from the Sahelian north to the humid rainforests of the south, are undergoing significant climatic shifts, including desertification, irregular rainfall, flooding and land degradation (Federal Ministry of Environment, 2021). Because farming and herding remain the foundation of rural livelihoods, the impact of these changes has been profound. Farmers dependent on rainfall for crops and herders reliant on grazing land and water increasingly compete for shrinking resources. Migration routes that were historically negotiated and managed through traditional agreements have become flashpoints for recurring violence as climate stressors overwhelm customary conflict resolution mechanisms (Onuoha, 2008; Okoli & Atelhe, 2014). Farmer–herder migration and disputes are not new in Nigeria, but climate change has transformed them into one of the most serious security threats facing the country today.

Desertification in northern Nigeria has forced pastoralists southward, bringing them into contact with densely populated farming areas already grappling with land scarcity. At the same time, agriculture has expanded into marginal lands to cope with population growth and urbanisation, blocking traditional grazing corridors (Blench, 2010; Adelakun, Adurogbangba & Akinbami, 2015). The result has been increasingly violent confrontations, displacement of communities, destruction of property and disruption of food production. Reports indicate that farmer–herder conflicts now account for some of the highest levels of violence in the country, sometimes surpassing fatalities from insurgencies (Amnesty International, 2018; SBM Intelligence, 2020).

The conflict is no longer merely about land or water; it has taken on ethnic, cultural and political dimensions. The southward migration of Fulani herders has deepened mistrust between pastoralists and host farming communities, creating conditions where disputes escalate into identity-based violence (Olaniyan, Francis & Okeke-Uzodike, 2015). Weak governance and fragile institutions have compounded the crisis, as traditional mechanisms of mediation erode and state responses remain reactive, fragmented and overly militarised. While policy interventions such as grazing reserve and anti-open grazing laws have been attempted, they have not addressed the root environmental and livelihood pressures that fuel the conflict. Scholarly contributions have shed light on various dimensions of the problem. Research by Federal Ministry of Environment, 2021; Food and Agriculture Organization [FAO], 2019; Amnesty International, 2018; Okoli and Ogadimma, 2016; Adelakun, Adurogbangba and Akinbami, 2015, has explored the socio-cultural and institutional barriers affecting affected communities, while has taken on political and cultural dimensions, deepening mistrust and dividing communities. Olorunfemi, Akanmu & Salisu, 2024 and Okoli and Ogadimma (2016) have examined motivations and structural barriers to peaceful coexistence. However, a significant gap remains in systematically analysing the nexus between climate change and farmer–herder migration conflicts in Nigeria. Specifically, limited attention has been paid to how environmental stressors interact with socio-economic and political dynamics to fuel violence and how these conflicts in turn threaten livelihoods and national food security.

The farmer–herder conflict in Nigeria is no longer a localised or seasonal issue but a nationwide security and development challenge. It directly undermines the country's progress towards achieving the United Nations Sustainable Development Goals, particularly Goal 2 (Zero Hunger), Goal 5 (Gender Equality), Goal 13 (Climate Action), Goal 16 (Peace, Justice and Strong Institutions) and Goal 11 (Sustainable Cities and Communities). Understanding the climate-conflict nexus is therefore urgent for policy, scholarship and practice. This study aims to provide such an understanding by evaluating how climate change shapes farmer–herder migration conflicts in Nigeria. It focuses on the environmental causes and implications of the conflict, the socio-economic and political drivers and the impacts on livelihoods and food security, offering a comprehensive and critical evaluation. It is structured into five parts: the introduction, which establishes the rationale and aim of the research; the literature review, which synthesises global and local debates; the methodology, which explains the desktop review approach; the findings and discussion, which analyse the nexus between climate change and farmer–herder conflicts; and the conclusion, which provides policy implications and recommendations for building resilience and fostering sustainable peace.

1. LITERATURE REVIEW

This section reviews the concept of climate change and conflict theory, which together inform the development of a conceptual framework referred to as the concept of farmer–herder conflicts. It further examines scholarly works on key dimensions of climate change in Nigeria, such as rainfall variability, rising temperatures, drought, flooding, and desertification, and their implications for resource scarcity. The review also explores the links between climate change, migration and conflict in Nigeria, as well as agricultural and grazing practices that shape farmer–herder relations. Finally, it identifies the gaps in existing literature that this study seeks to address.

1.1 Concept of Climate Change

Climate refers to the long-term average of weather conditions such as temperature, rainfall, humidity and wind patterns over a significant period, usually decades or centuries.

While natural processes such as volcanic eruptions, plate tectonics, variations in the earth's orbit and El Niño Southern Oscillation (ENSO) contribute to climate variability, recent shifts in the earth's climate are overwhelmingly attributed to human activities (Odjugo, 2010). The burning of fossil fuels, industrial emissions and deforestation have resulted in an unprecedented accumulation of greenhouse gases (GHGs), including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NOx), in the atmosphere. These gases trap heat, causing global warming and subsequent climate instability (IPCC, 2007).

The Intergovernmental Panel on Climate Change (IPCC, 2007) defines climate change as a persistent alteration in the state of the climate, observable through changes in mean climatic variables or variability and lasting for decades or longer. Climate change is therefore distinct from climate variability, which refers to shorter-term fluctuations that occur naturally across seasons or years. Scholars such as Parry et al. (2007) emphasise that climate change is directly or indirectly linked to anthropogenic activities and its impacts extend beyond environmental degradation to socio-economic and political instability. In Nigeria and across sub-Saharan Africa, the manifestations of climate change are severe: prolonged droughts in the north, desertification of the Sahel, increased flooding in southern states and erratic rainfall patterns that disrupt agricultural cycles (Federal Ministry of Environment, 2021). Given that over 70% of Nigeria's population depends on agriculture and pastoralism for livelihood, these disruptions have critical implications for food security, social cohesion and sustainable development.

1.2 Conflict Theory

Conflict theory, pioneered by Karl Marx in the 19th century, provides a powerful foundational information for understanding the structural inequalities and power struggles embedded in society. Marx (1867/1990) argued that society is stratified into social classes, with the ruling bourgeoisie controlling resources and exploiting the working proletariat, inevitably leading to conflict. Modern conflict theorists expand this perspective, highlighting how inequalities in access to economic opportunities, political power, and cultural recognition lead to recurring struggles.

These struggles are often expressed in the form of protests, political activism, or violence (Hurst, 2019). At its core, conflict theory assumes that conflict is inherent in human society because resources are finite, while social groups compete for survival, control and dominance. Applied to the Nigerian context, this framework sheds light on the recurrent tensions between farmers and herders, who compete for limited natural resources, especially land and water. Farmers often see pastoralists as intruders threatening cultivated land, while herders perceive farming communities as obstacles to their traditional migratory routes. These competing claims reveal deeper structural inequalities: weak land tenure systems, exclusionary policies and lack of access to political power and justice mechanisms for vulnerable groups.

Conflict theory therefore provides a basis for interpreting farmer–herder clashes not as isolated incidents but as outcomes of systemic inequalities and imbalances in resource allocation. It also explains how these disputes often escalate into broader ethnic or religious hostilities when manipulated by political elites or amplified by cultural stereotypes. By situating farmer–herder tensions within a broader socio-political framework, conflict theory emphasised the need for equitable governance, institutional reforms and inclusive resource management strategies to reduce the drivers of violence.

1.3 Concept of Farmer–Herder Conflicts

The concept of farmer–herder conflicts describe the persistent and escalating disputes between sedentary farming populations and nomadic or semi-nomadic pastoralists, particularly in the core agrarian, non-agrarian and other agriculturally fertile regions. At the heart of the conflict lies competition for scarce resources, primarily land and water, which have become increasingly strained due to population growth, agricultural expansion and climate-induced degradation (Adisa & Adekunle, 2010). Historically, these groups maintained symbiotic relationships, with farmers exchanging crop residues for manure from livestock and herders accessing agreed grazing corridors (Blench, 2010). However, this fragile balance has deteriorated in recent decades as environmental change and socio-political pressures converge.

In Nigeria, climate change has accelerated desertification in the north, reduced water bodies and diminished pasturelands, forcing herders to migrate further south in search of resources (McGregor, 2014; Mercy Corps, 2018). At the same time, farmers, driven by population growth and commercialisation of agriculture, have expanded into traditional grazing areas, blocking migratory routes. These competing pressures increase the frequency and intensity of confrontations. Furthermore, weak governance structures, ineffective land policies and the collapse of traditional mediation mechanisms have removed critical avenues for conflict resolution. In many cases, disputes escalate into violent clashes with devastating consequences, including displacement, loss of lives, destruction of livelihoods and deepening ethnic and religious polarisation (Amnesty International, 2018; Okoli & Ogadimma, 2016).

From a conceptual standpoint, farmer–herder conflicts are best understood as the intersection of environmental stressors (climate change impacts), structural inequalities (unequal access to land and resources) and socio-political dynamics (ethnic identity, weak governance and political manipulation). This synthesis of the climate change perspective with conflict theory offers a holistic lens for evaluating the crisis. It emphasised that solutions must move beyond militarised responses and restrictive legislation to include climate adaptation strategies, inclusive policies, financial support for both groups and grassroots conflict resolution mechanisms.

1.4 Dimensions of Climate Change in Nigeria (Rainfall, Temperature, Drought, Flooding, Desertification)

Climate change in Nigeria presents itself in multiple dimensions that cut across rainfall variability, rising temperatures, prolonged droughts, devastating floods and widespread desertification. These phenomena are reshaping ecosystems, endangering livelihoods and deepening vulnerabilities in both rural and urban settings. The implications are especially critical because Nigeria’s economy and population heavily depend on agriculture and natural resources for survival.

Oguntoyinbo et al. (2020) examined long-term climatic data between 1960 and 2017 using indices such as the highest daily maximum temperature, lowest daily minimum temperature, highest daily rainfall and Rx5day.

Their findings revealed that temperature extremes have risen significantly across the country, with maximum temperatures increasing more sharply than minimum ones. The study also established that rainfall extremes have become more frequent in the northern regions, but the patterns are highly varied across these regions in both space and time, making adaptive strategies difficult to generalise. Similarly, Oluseyi et al. (2018) investigated the Southwest region of Nigeria from 1961 to 2010 and found consistent increases in maximum temperature extremes, alongside irregularities in rainfall intensity and distribution. Their work further highlighted how such changes threaten agricultural productivity, particularly through reduced crop yields, increased pest invasions and heat stress on livestock.

Specifically, in Northern Nigeria, Daramola et al. (2019) assessed climate extremes between 1979 and 2016 and observed a persistent rise in maximum temperature events. They noted that rainfall intensity had increased in some areas but decreased in others, creating unpredictable agricultural and hydrological outcomes. The study stressed that rising temperatures combined with rainfall uncertainty will significantly undermine water availability, rural livelihoods and food security. Overall, the evidence across these studies shows that climate change in Nigeria is characterised by sharp regional disparities in rainfall and temperature, which in turn complicate policy responses. These climatic dimensions are central to understanding the rising vulnerabilities of both farmers and herders, as shifts in rainfall and temperature patterns directly determine the availability of water, grazing pastures and arable land.

1.4.1 Climate Change and Natural Resource Scarcity

One of the most direct outcomes of climate change in Nigeria is the intensification of natural resource scarcity, particularly in relation to land and water. Erratic rainfall, recurrent droughts and desertification in the north have diminished grazing reserves, while floods and land degradation in the middle belt and southern regions have reduced the quality and quantity of arable farmland. As a result, both farmers and pastoralists face increasing competition over shrinking resources, which serves as a catalyst for violent disputes. Kanchan (2022) explains that climate change worsens humanitarian crises by altering both the nature and severity of resource-based vulnerabilities.

Scarcity can arise either from the uneven distribution of abundant high-value resources or from outright shortages of basic necessities such as land and water. In Nigeria, it is the latter that dominates, as population growth, poor land management and environmental degradation intersect with climate change to create acute shortages. These shortages drive tensions as local demand for farmland, grazing land and freshwater far exceeds supply, generating conditions ripe for conflict.

The security risks linked to global warming are, therefore, inseparable from development. Food insecurity, inadequate access to water, desertification and population displacement are combining with weak institutional capacity to intensify Nigeria's fragility. In regions where resource scarcity coincides with high population pressures and poor governance, climate change multiplies the risk of violent conflict. The Nigerian case illustrates this clearly: dwindling water and pasture in the north force herders to migrate southward into farming zones, igniting competition that easily escalates into violent confrontations. Evidence from across Africa shows that such scarcity-induced conflicts are not unique to Nigeria. The prolonged Darfur conflict in Sudan, disputes over water in Ethiopia's Tigray region and climate-induced violence in the Sahel highlight the broader pattern of climate insecurity (Kanchan, 2022). For Nigeria, farmer–herder clashes are a local manifestation of this global trend. Moreover, high-profile security crises, such as mass kidnappings in resource-stressed regions, illustrate how climate change intertwines with insecurity, economic hardship and weak governance to create multi-layered threats.

However, natural resource scarcity linked to climate change is not only an environmental issue but also a political and developmental challenge. As Nigeria grapples with rainfall irregularities, temperature extremes, desertification and flooding, the competition over scarce land and water has become a central driver of conflict. Addressing this challenge requires integrating climate adaptation strategies with resource governance, community-based conflict resolution and national development planning.

1.4.2 Climate Change, Migration and Conflict in Nigeria

Climate change has become one of the most significant drivers of migration and conflict in Nigeria, shaping socio-economic, environmental and political dynamics across the country. Rising temperatures, prolonged droughts, desertification and unpredictable rainfall patterns directly threaten livelihoods, particularly in agriculture and pastoralism, which remain the backbone of rural economies. In northern Nigeria, advancing desertification and the shrinking of water bodies such as Lake Chad have drastically reduced arable land and grazing fields, forcing pastoral communities to migrate southward in search of pasture and water. This migration often sparks clashes with farming communities as competition over scarce resources intensifies, making the farmer–herder conflict one of the most visible manifestations of how environmental stress linked to climate change fuels migration and violent conflict.

Beyond the north, similar patterns are observed in other ecological zones. In the Niger Delta region, rising sea levels, recurrent flooding and oil-induced environmental degradation have displaced communities and disrupted fishing and farming activities. These disruptions have generated grievances that exacerbate already fragile relationships between local populations, oil companies and the state. Urban areas also face increased migration pressures, as displaced rural populations move to cities, straining infrastructure, housing and employment opportunities, which in turn heighten social tensions and insecurity.

Importantly, climate-induced migration often intersects with Nigeria's pre-existing ethnic, religious and political divides. For instance, the migration of herders into predominantly Christian farming communities in the Middle Belt has acquired an ethnic and religious dimension, deepening mistrust and fuelling cycles of violence. What begins as environmental stress is therefore amplified by socio-political fault lines, escalating into widespread insecurity. Without proactive policy interventions, such as climate adaptation measures, sustainable land and water management and comprehensive conflict resolution frameworks, Nigeria risks worsening humanitarian crises, large-scale displacement and national insecurity.

Thus, climate change, migration and conflict are deeply interconnected in Nigeria, underscoring the need to view environmental issues not only as ecological challenges but also as critical threats to peace, security and development.

1.4.3 Agricultural and Grazing Practices in Nigeria

Agricultural and grazing practices in Nigeria have long been shaped by both cultural traditions and government policies, many of which aimed to regulate land use and reduce tensions between farmers and pastoralists. Grazing reserves in Nigeria date back to the pre-colonial era, when Fulani pastoralists demarcated lands for livestock grazing after their conquest and settlement in northern Nigeria (Bako and Ingawa, 1988). The British colonial administration formalised this system in the 1940s, attempting to separate grazing land from farmland. However, these efforts faltered, as imposed land-use controls failed to account for the complex demographic and economic dynamics of pastoralist systems (Frantz, 1981).

The Nigerian Grazing Reserve Act of 1964 was later introduced to provide dedicated grazing lands for pastoralists, thereby encouraging sedentarisation and reducing conflicts with farmers. The Act was also intended to address broader challenges of cattle markets and disease control while providing pastoralists with social amenities to improve productivity (Ingawa et al., 1989; Ibrahim, 2012). Yet, despite its passage, implementation was weak (CIEL, 2006). In response to declining cattle production and rising importation, estimated at 23% from neighbouring Sahel countries, the government launched the National Agricultural Policy in 1988. This policy mandated that at least 10% of Nigeria's landmass (9.8 million acres) be allocated to grazing reserves. However, only 2.82% was acquired, amounting to just 313 reserves nationwide (Ibrahim, 2012).

Despite these policies, conflicts between arable crop farmers and pastoralists remain pervasive. Historically, clashes arose mainly from overlaps between farmland and cattle routes, where farmers encroached on designated grazing paths. Today, however, the conflict has escalated, taking on ethnic and religious dimensions, while government and community leaders have made limited efforts to implement durable solutions.

Seasonal variations also play a role, with the rainy season being the most intense period of clashes due to peak farming and grazing activities. Researchers have linked these conflicts to climate change, particularly desertification and aridity, which reduce grazing land and force herders to migrate southwards (Abbass, 2012; Okoli, Enyinnia, Elijah & Okoli, 2014). However, there remains little consensus between farmers and pastoralists regarding the direct causes of conflict. Farmers often cite the destruction of crops, farmland and irrigation infrastructure by cattle as key triggers, while pastoralists point to blocked stock routes, encroached grazing lands and restricted access to water as the primary drivers (De Haan, 2002). These disputes have escalated into widespread violence, with recurring reports of killings, destruction of property and large-scale displacement regularly covered in Nigerian media. The persistence of these clashes highlights the failure of existing policies and institutions to resolve tensions.

1.5 Literature Gap

Despite a growing body of literature linking climate change, migration and farmer–herder conflicts in Nigeria, significant gaps remain in policy-oriented research. Many studies have examined the environmental dimensions of the conflict, focusing on climate variability, desertification and rainfall changes as drivers of migration and competition (Blench, 2010; Adelakun, Adurogbangba & Akinbami, 2015). Others have explored socio-political and cultural dimensions, highlighting ethnic and religious fault lines (Okoli & Atelhe, 2014; Olaniyan, Francis & Okeke-Uzodike, 2015). However, few studies have integrated these perspectives to show how climate change interacts with socio-economic and governance failures to escalate farmer-herders conflicts. Moreover, existing scholarship has not sufficiently examined the long-term implications of farmer–herder conflicts on food security, rural development and the attainment of the Sustainable Development Goals (SDGs) in Nigeria. This gap emphasised the need for a holistic evaluation that situates farmer–herder conflicts within the broader nexus of climate change, governance and sustainable development, while also identifying adaptive strategies for peaceful coexistence and resilience.

2. METHODOLOGY

This study employs a qualitative research design, relying on a desktop review and expert judgment approach to examine the nexus between climate change and farmer–herder conflicts in Nigeria. Data were sourced from peer-reviewed journal articles, textbooks, book chapters, policy documents, government publications and credible reports from international organisations such as the IPCC, FAO and World Bank. The inclusion criteria focused on works addressing climate variability, migration, resource scarcity and their socio-economic and political implications within Nigeria and comparable Sub-Saharan African contexts.

The collected data were subjected to thematic analysis to achieve the objectives. Particular emphasis was placed on examining how environmental factors, such as rainfall variability, drought, flooding, desertification and rising temperatures, intersect with governance failures and socio-political factors to intensify farmer–herder conflicts. Expert judgment was further applied to contextualise findings within Nigeria's policy environment and to assess the implications for livelihoods, food security and sustainable development. The data generated were analyzed qualitatively.

3. RESULTS AND DISCUSSION

The analysis reveals that climate change is a central driver in reshaping farmer–herder relations in Nigeria, transforming what were once manageable seasonal interactions into persistent, violent conflicts. Evidence from multiple studies indicates that climate variability, rising temperatures, desertification, flooding and erratic rainfall have significantly undermined the natural resource base that sustains both crop farming and livestock rearing (Abbass, 2012; Amnesty International, 2018). In northern Nigeria, desertification and the shrinking of water bodies, such as Lake Chad, have forced pastoralists to migrate southward in search of pasture and water. This southward migration has brought herders into increasingly direct and hostile competition with densely populated farming communities in the Middle Belt and southern states. Unlike earlier patterns of cooperation mediated by traditional institutions, these encounters now escalate quickly into violence, leading to loss of lives, displacement and destruction of property.

The findings also emphasis that climate change does not act in isolation but interacts with deep-rooted structural inequalities and weak governance. Inadequate land-use planning, ineffective agricultural policies and the absence of climate-resilient infrastructure have worsened the vulnerability of both farmers and herders (Kwaja & Adelehin, 2017). Population growth and the expansion of commercial agriculture have further encroached on grazing lands, intensifying competition. Moreover, the politicisation of farmer–herder conflicts, particularly since the return to democracy, has added ethnic and religious undertones, transforming resource-based disputes into identity-driven violence that undermines national integration (Nwosu, 2017). This dynamic confirms the view of scholars who argue that the climate–conflict nexus is best understood as a complex interplay between environmental stress and socio-political fragility (Akinyemi & Olaniyan, 2017; Ide, 2015).

An important implication of the results is the recognition of climate change as a conflict multiplier. Climate-induced stress on land and water resources aggravates socio-economic inequalities and exposes the weakness of governance institutions in conflict mediation. The recurrent clashes not only disrupt agricultural production and food supply chains but also destabilise rural economies, exacerbating poverty and threatening Nigeria's food security. Furthermore, recurring violence erodes trust between communities and weakens traditional systems of cooperation that once helped to regulate seasonal migration and land use. In this way, the farmer–herder conflict exemplifies how climate change can deepen existing vulnerabilities and transform livelihood crises into national security threats.

To address these challenges, the findings point towards several policy-oriented strategies. First, climate adaptation interventions such as land restoration, afforestation and irrigation infrastructure are essential to expand the resource base and reduce competition. Second, reforms to land tenure and agricultural policy should prioritise equity, by balancing the needs of farmers and herders through negotiated frameworks that integrate grazing reserves, ranching and regulated transhumance. Third, strengthening conflict resolution mechanisms at the grassroots level is critical to rebuilding trust and preventing disputes from escalating into violence.

Fourth, the depoliticisation of the conflict is necessary, requiring political actors to avoid exploiting ethnic or religious divisions for electoral gains. Finally, integrating early warning systems with community-based monitoring can provide rapid responses to emerging resource disputes.

The broader implication is that the nexus between climate change and farmer–herder conflict cannot be addressed solely through environmental or security lenses. It demands an integrated approach that combines climate resilience, inclusive governance and sustainable development. This aligns with global commitments under the United Nations Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 13 (Climate Action) and SDG 16 (Peace, Justice and Strong Institutions). By situating climate change as both an environmental and governance challenge, Nigeria can transform the current cycle of violence into an opportunity for building resilience, strengthening livelihoods and promoting peaceful coexistence between farmers and herders.

3.1 Socio-Economic and Political Drivers of Farmer–Herder Conflicts

Farmer–herder conflicts in Nigeria are shaped not only by environmental stressors but also by deeply embedded socio-economic and political factors that interact to intensify violence. At the socio-economic level, rapid population growth, urbanisation and agricultural expansion have drastically reduced communal grazing lands and water points, increasing the struggle between sedentary farmers and nomadic herders for limited resources. Rural poverty, unemployment and widening inequality create fertile ground for conflict, as many young people, facing exclusion and lack of opportunities, are easily mobilised into violent confrontations, often framed as group protection or survival strategies. This economic marginalisation feeds into broader social tensions, especially as competition over livelihoods increasingly overlaps with ethnic and religious divides.

Ethnic identity plays a significant role in escalating these conflicts. Most pastoralists belong to the Fulani ethnic group, who are predominantly Muslim, while many farming communities in central and southern Nigeria are largely Christian.

What begins as disputes over land, water, or grazing rights often takes on ethnic and religious dimensions, deepening mistrust and perpetuating cycles of retaliation. These identity-driven narratives make local disputes harder to resolve and contribute to widespread insecurity. Politically, weak governance, corruption and poor land tenure systems reinforce these divisions. In many cases, land allocation policies are unclear or inconsistently enforced, creating uncertainty and breeding resentment. Furthermore, the absence of effective conflict resolution mechanisms fosters impunity, as violent actors rarely face prosecution. Political elites, in turn, often manipulate these conflicts for electoral advantage, presenting themselves as defenders of ethnic or religious constituencies, thereby institutionalising divisions and undermining national cohesion.

Institutional and policy failures also play a crucial role. Initiatives such as grazing reserve policies, ranching programmes and livestock transformation plans have suffered from poor design, inadequate funding, or lack of political will, leaving both farmers and herders feeling excluded and unprotected. Weak state capacity to enforce agreements or mediate disputes has further eroded trust in government. Adding to these domestic challenges, cross-border migration of pastoralists from neighbouring Sahelian countries and the widespread availability of small arms have introduced a transnational dimension, intensifying the scale and lethality of clashes. Taken together, these socio-economic and political drivers demonstrate that farmer–herder conflicts in Nigeria are not merely environmental disputes but multidimensional crises rooted in structural weaknesses of governance, inequitable resource management and fragile national integration. Addressing these drivers therefore requires holistic strategies that go beyond environmental adaptation to include institutional reforms, inclusive economic development and stronger governance systems aimed at fostering trust and social cohesion. Effective conflict resolution must also incorporate community-based peacebuilding mechanisms that empower local actors to participate in decision-making processes. Strengthening early warning systems and promoting dialogue between farmers and herders can help prevent escalation before violence erupts.

3.2 Impact of Climate Change and Farmer–Herder Conflict on Livelihoods and Food Security

The farmer–herder conflict in Nigeria has had devastating consequences on rural livelihoods and national food security. Livelihood systems, which are predominantly agrarian in nature, have been repeatedly disrupted as violent clashes destroy farmlands, livestock and infrastructure essential for production and trade. In states such as Benue, Plateau, Taraba, Nasarawa and Kaduna, regarded as the "food basket" of the nation, recurring violence has reduced crop yields, devastated livestock herds and displaced farming households. This has weakened household income streams, eroded coping mechanisms and deepened rural poverty. For pastoralists, the conflict has resulted in cattle rustling, loss of grazing land and the collapse of traditional transhumance systems, further threatening their livelihood sustainability.

Food security has been severely undermined, as recurrent violence directly impacts all four dimensions of food security, availability, accessibility, utilisation and stability. Food availability is reduced as farmers abandon farmlands and herders lose livestock, resulting in lower production of staples such as maize, rice, yam and sorghum, as well as reduced supply of meat and dairy. Accessibility is constrained as markets are destroyed, rural roads become insecure and food prices rise due to scarcity and disrupted supply chains. Utilisation is impaired as internally displaced persons (IDPs) suffer malnutrition, poor dietary intake and heightened susceptibility to diseases, particularly among children and women. Finally, the stability of food systems is compromised, as recurrent violence prevents long-term investments in agriculture, worsens climate vulnerability and increases dependence on costly imports to meet local demand.

The implications extend beyond food to wider human security. Displacement forces households into overcrowded camps or host communities where access to shelter, clean water and healthcare is limited, increasing exposure to communicable diseases such as cholera, typhoid and malaria. Education is interrupted as schools are destroyed or abandoned, while children in displaced families are forced into child labour, street begging, or early marriages.

The erosion of livelihoods also heightens social vices such as theft, banditry and recruitment into armed groups, further destabilising already fragile communities. Collectively, these impacts undermine Nigeria's progress towards the Sustainable Development Goals (SDGs), especially SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-Being) and SDG 16 (Peace, Justice and Strong Institutions). If left unaddressed, the dual pressures of climate change and violent conflict threaten to lock millions of Nigerians into a cycle of poverty, hunger and insecurity, thereby weakening national resilience and economic growth.

CONCLUSION

The farmer–herder conflict in Nigeria has evolved into a multidimensional crisis where climate change, resource scarcity, governance failures and identity politics intersect to produce recurring cycles of violence. Rising temperatures, desertification, flooding and erratic rainfall have altered Nigeria's ecological balance, disrupting the livelihoods of both farmers and herders and heightening competition over land and water resources. What once existed as seasonal and manageable interactions between farmers and pastoralists has now escalated into violent confrontations due to weakened traditional systems, poor governance and the politicisation of ethnic and religious identities. These conflicts not only disrupt agricultural production and displace rural populations but also undermine food security, national stability and Nigeria's progress toward achieving the Sustainable Development Goals (SDGs), particularly those on hunger, poverty, peace and climate action. The persistence of the crisis reflects deeper systemic inequalities in access to land, resources and political representation, with climate change acting as a catalyst that transforms ecological stress into violent conflict.

Addressing this challenge requires strategies that go beyond militarised interventions. There is an urgent need for climate adaptation measures such as investment in drought-resistant crops, irrigation schemes, reforestation and sustainable water management, which can reduce the environmental stressors that fuel migration and clashes.

Equitable land and resource management must also be prioritised through reforms in land tenure, the demarcation of grazing corridors and the rehabilitation of grazing reserves to guarantee fair access for both farmers and pastoralists. Strengthening governance institutions to mediate disputes transparently and enforce policies consistently is equally essential. At the community level, fostering dialogue platforms, cooperative ventures and trust-building initiatives will help counter identity-based divisions and promote peaceful coexistence. Creating alternative livelihoods through vocational training, entrepreneurship support and financial inclusion will reduce overdependence on farming and herding, thereby easing pressure on natural resources. In addition, the establishment of early warning systems, intelligence-driven security responses and regional cooperation to manage cross-border migration and curb the proliferation of small arms will strengthen conflict prevention. Only through these integrated strategies that combine environmental adaptation, equitable governance and community-driven peacebuilding can Nigeria build resilience, safeguard food security and ensure sustainable peace.

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