Typological analysis and characterization of apple production systems in a semi-arid region: case of Khenchela (Northeast Algeria)

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Abstract

This study conducts a typological characterization and analysis of apple production systems in the semi-arid region of Khenchela, Northeast Algeria, a region contributing 25% (181,546 tonnes) of the national apple production, valued at USD 178,628,080 in 2023. The research identifies the structural, technical, and socio-economic determinants shaping apple farming practices in this agro-climatic context. A comprehensive survey was conducted, integrating field data collection and statistical analysis, with a focus on farm size, management practices, irrigation systems, varietal preferences, and socio-demographic profiles of farmers, including age, education level, and technical expertise.

The analysis revealed four distinct typologies of apple production systems, predominantly characterized by small-scale farms averaging 2 hectares in size. These farms are primarily farmers with an average age of about 48 with intermediate education levels and a proficient understanding of modern agricultural techniques. Intensive input regimes, including chemical fertilizers, growth regulators and, pruning, are employed to optimize commercial production quality. mechanization is observed, with 20% of farmers owning tractors, either individually or through collective arrangements. Drip irrigation systems are implemented on 95% of the farms, reflecting advanced water-use efficiency. The dominant cultivar is Golden Delicious, complemented by red apple varieties such as Gala Star, Top Red, and Royal Gala.

The findings underscore the adaptability of apple production systems in Khenchela's semi-arid climate, characterized by cool winters and limited annual precipitation (300–400 mm). However, methodological constraints, such as limited farmer availability and survey non-participation, posed challenges to data collection. This study provides critical insights into the operational dynamics of apple farming in the region, offering a foundation for targeted interventions to enhance productivity, sustainability, and resilience in the face of climatic and socio-economic challenges.

Keywords: Apple orchard**,** Intensive growing apple, Production system, Sustainability, Typology.

1. Introduction

The apple (*Malus domestica*) stands as one of the most economically significant fruit crops globally, with an annual production of 87 million tons and an estimated economic value exceeding $45 billion in 2019 (FAOSTAT, 2020). As a cornerstone of temperate fruit cultivation, apple production plays a pivotal role in rural economies, generating direct and indirect employment while enhancing the livelihoods of millions of people (Abdessemed et al., 2022). The apple supply chain supports a wide range of stakeholders, from growers to distributors, underscoring its importance in global agricultural systems. However, the sustainability of apple production systems necessitates a holistic approach that addresses environmental, economic, and social dimensions to ensure they are "environmentally non-degrading, technically appropriate, economically viable, and socially acceptable" (FAO, 1989; Pretty, 2008).

In the Mediterranean basin, fruit arboriculture has experienced significant expansion, driven by favourable agroclimatic conditions and increasing market demand. In Algeria, apple cultivation is deeply embedded in the socio-economic fabric of rural communities, serving as a critical source of income and employment. To bolster domestic production, the Algerian government has implemented strategic policies, including the suspension of apple imports and the introduction of the Plan National of Development Agricole (PNDA). This grant program aims to promote apple cultivation in arid and mountainous regions, thereby accelerating the growth of the fruit production sector. Historically, the central regions of Algeria: Médéa, Blida, and Ain Defla accounted for 25% of the total area dedicated to apple production, with 7,400 hectares under cultivation (Sahraoui, 2014). Through the PNDA initiative, apple cultivation has expanded to regions such as Batna, Khenchela, Mascara, Tiaret, Djelfa, and Sidi Bel Abbés, which have now emerged as the principal apple-producing areas in the country (Abdessemed et al., 2022).

In Khenchela, apple cultivation has reached 6,121 hectares, contributing 25% of Algeria's national production during the 2022/2023 season, according to regional agricultural authorities. Intensive apple production in this semi-arid region relies on high-yielding varieties, trellis systems, frequent weeding, and the extensive application of fertilizers and pesticides to maximize yields (Alaphilippe et al., 2013;

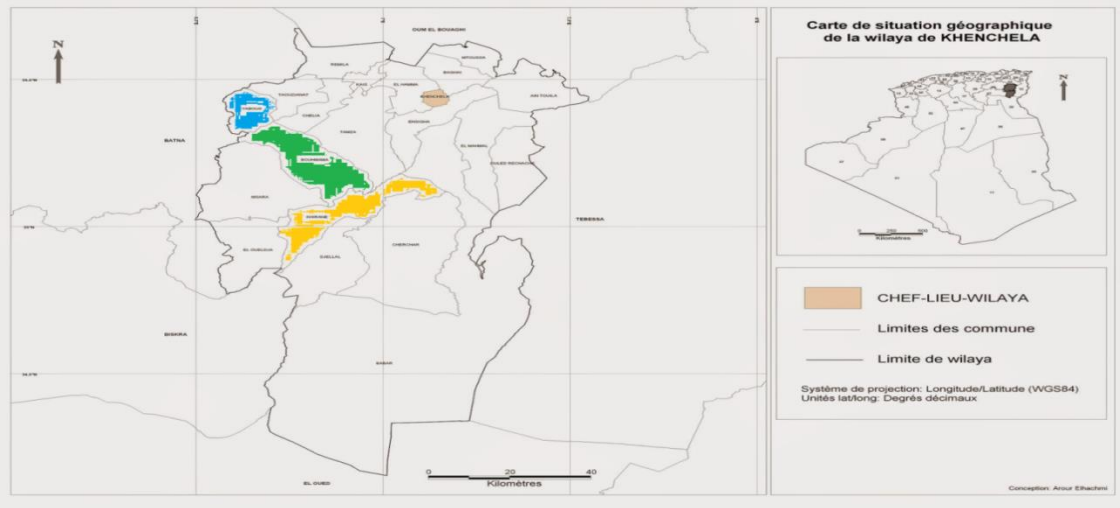
Cai et al., 2021). While this expansion has driven economic growth and social development, it has also raised concerns about environmental sustainability. Agricultural practices, including intensive apple farming, can lead to soil degradation, salinization, excessive water abstraction, and a reduction in genetic diversity, posing long-term risks to ecosystem health and agricultural productivity (FAO, 2002).

Over the next three decades, the environmental impacts of agriculture are expected to persist, with some challenges intensifying at a slower rate and others potentially regressing. A critical challenge for modern agriculture lies in reconciling agronomic productivity with ecological conservation and socio-economic viability to maintain or restore ecosystem multifunctionality (Manning et al., 2018). The agricultural sector must address pressing issues such as biodiversity loss, environmental degradation, and income instability for farmers to ensure sustainable land management practices (Lorenzo Baima, 2024).

This study focuses on the typological characterization of apple production systems in the semi-arid region of Khenchela, Northeast Algeria. Through a comprehensive survey based on technical and socio-economic criteria conducted in three key regions Bouhmama, Yabous, and Khiran. The research aims to identify prevailing agricultural practices, trends, and challenges in apple production. The findings will provide a scientific foundation for promoting sustainable apple cultivation, safeguarding natural resources, and mitigating environmental risks associated with intensive farming practices. By elucidating the dynamics of apple production systems in Khenchela, this study seeks to contribute to the development of strategies that harmonize productivity, environmental stewardship, and socio-economic resilience in the region.

2. Material et methods

2.1 Study Area and Context of Apple crops



2.1.1 Geographical Location

The Wilaya of Khenchela is located in northeastern Algeria, within the Aurès mountain range. Geographically positioned between the Steppic Range and the High Plateaux, the region exhibits agro-pastoral and Saharan forestry characteristics. It encompasses an area of approximately 9,715 km², with a population of around 469,510 inhabitants. Administratively, the region is divided into 6 districts (*dayras*) and 21 municipalities (M.I.C.L., 2024).

Fig. 1: Study area (Khenchela State) where the three study areas in Bohmama were mentioned in green, yabous in blue and Khiran in yellow on the map of Khenchela source: (Découpage administratif de l'Algérie & Monographie publier par lhachmi Arour sur le site: https://decoupageadministratifalgerie.blogspot.com/2014/10/cartegeographiqueKHENCHELA.html)

The topography of Khenchela is dominated by four mountainous massifs: Benimelloul, Beni Oudjana, Ouled Yagoub to the west, and the Nememcha mountains to the south. These areas are largely barren, interspersed with valleys and depressions that contain small plains, such as

Kamouda and Mellagou, as well as the M'sara plateau. (BENIDIR MEKKI.1994).

2.1.2 Climate

Khenchela experiences a semi-arid climate characterized by cool winters and a prolonged dry season lasting approximately four months. The region is subject to high temperatures, intense solar radiation, low humidity, and strong winds, resulting in significant evapotranspiration rates (1,322 mm annually). Precipitation is highly variable, averaging 457.5 mm per year, with a pronounced north-south gradient ranging from 250 to 400 mm (BNEDER, 2017; BNEDER, 2019). These climatic conditions pose significant challenges for sustainable agriculture, necessitating the use of irrigation systems to support crop production.

the western part of Khenchela is classified as a dry zone, with annual precipitation levels ranging between 250 and 400 mm (Salhi & Ounassi, 2022). Additionally, the region experiences frequent frosts and large diurnal temperature variations, further exacerbating the constraints on agricultural productivity.

2.1.3 Agricultural Support Programs

Since Algeria's independence, agricultural development in Khenchela has been shaped by a series of government initiatives:

Self-Management and Agrarian Revolution (1962–1979): This period emphasized socialist policies, collective management, and state-controlled input supply and marketing systems.

Reforms of the State Agricultural Economy (1979–1999): Focused on stabilizing agricultural production through public subsidies and infrastructure development.

Stabilization, National Reconciliation, and Emergency Actions (2000–2008): Introduced diversified funding mechanisms to address specific agricultural needs.

Key funding mechanisms established during this period include:

- National Agricultural Investment Development Fund (FNDIA)
- National Fund for the Regulation of Agricultural Products (FNRPA)
- Guarantee Fund Against Agricultural Disasters (FGCA)
- Rural Development and Land Development Funds (FDRMVTC)
- Fund to Combat Desertification and Protect Rangelands (FLDPPS)
- Support Fund for Breeders and Small Farmers (FSAEPEA) (M.A.D.R., 2012).

A significant milestone in Khenchela's agricultural development was the 1973 technical and scientific cooperation agreement between Algeria and the Federal Republic of Germany. This agreement focused on agro-sylvo-pastoral development in mountainous regions and was implemented in three phases:

1. **Orientation Phase (1988–1992):** Planning and coordination of rural development measures.
2. **Promotion Phase (1993–1996):** Implementation of crop production, rangeland exploitation, and livestock management initiatives.
3. **Production Phase (1997–2003):** Scaling up agricultural and forestry activities.

Despite these efforts, farmers report that agricultural support services remain insufficient, particularly in terms of technical assistance and extension services. Private actors, such as seed sellers, often fill this gap by providing technical guidance.

2.2 Methodology:

To characterize the apple production systems in Khenchela, our study focuses on technical and socio-economic aspects, a field survey was carried out focusing on three key parameters: the farmer, the farm and the orchard management, a random sampling approach was adopted for 120 apple orchards distributed evenly over the three representative areas: Bouhmama, Yabous and Khirane.

2.2.1 Data Collection

A structured questionnaire was designed to gather data on:

- Farm characteristics (size, irrigation systems, input use…)
- Orchard management practices (varieties cultivated, fertilization, pest control..)
- Socio-economic factors (age, education level, access to credit, market linkages, income…)

Field visits were conducted to interview orchard owners and observe farming practices firsthand.

2.2.2 Data Analysis and Interpretation

Collected data were tabulated, coded, and analyzed using Principal Component Analysis (PCA) to identify patterns and relationships among variables. Statistical software was employed to process the data, enabling the classification of apple production systems into distinct typologies.

The results were interpreted to provide insights into the structural, technical, and socio-economic dimensions of apple production in Khenchela. This analysis serves as a foundation for recommending strategies to enhance productivity, sustainability, and resilience in the region's apple farming systems.

3. Results and Discussions:

3.1 Typology of farms

A statistical analysis of data using Principal Component Analysis (PCA) revealed four (04) groups of individuals representing farmers of the study area according to Fig 2 and 3

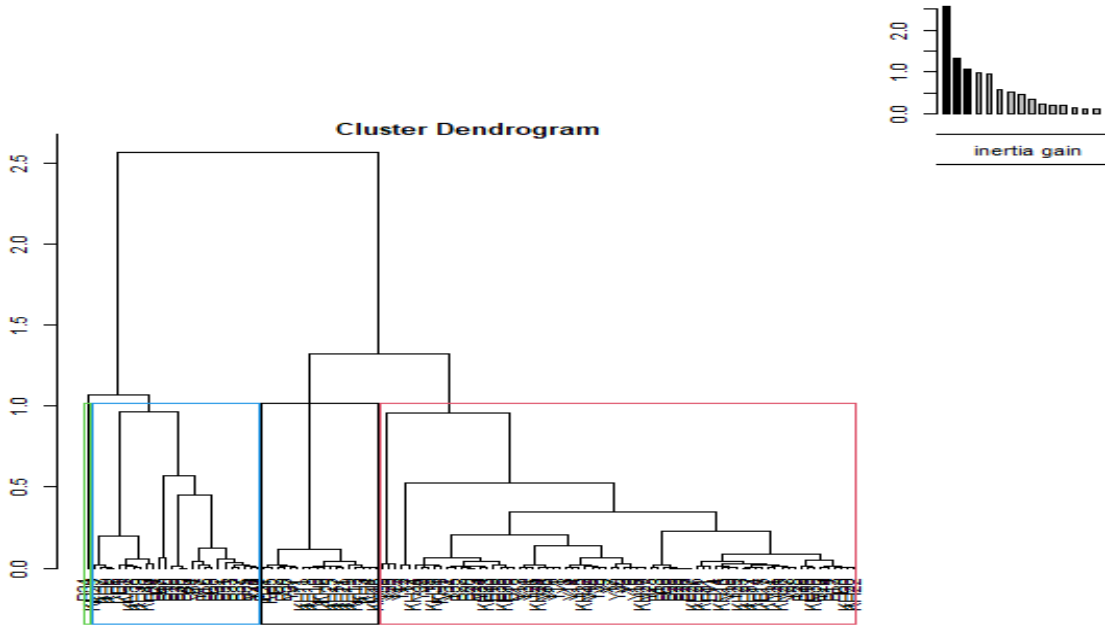


Fig. 2 – cluster dendrogram; present the four group of individuals wich represent a typological classes of apple production systems

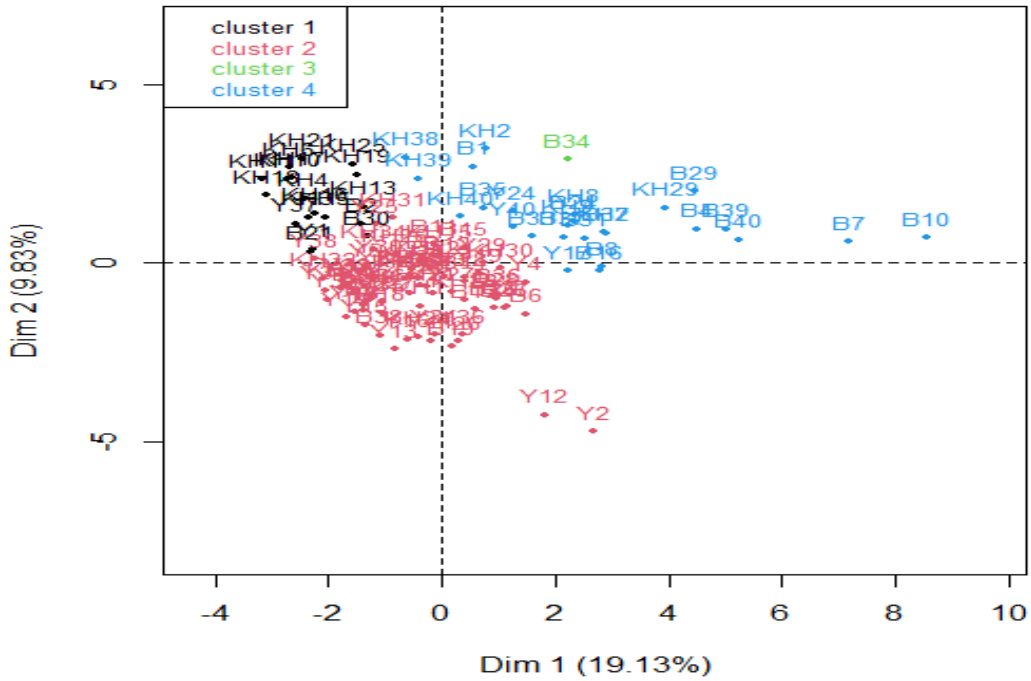


Fig. 3 Hierarchical Ascending Classification (typological classes) of production systems of apple growing; it presents the individuals of the four classes colored according to their clusters

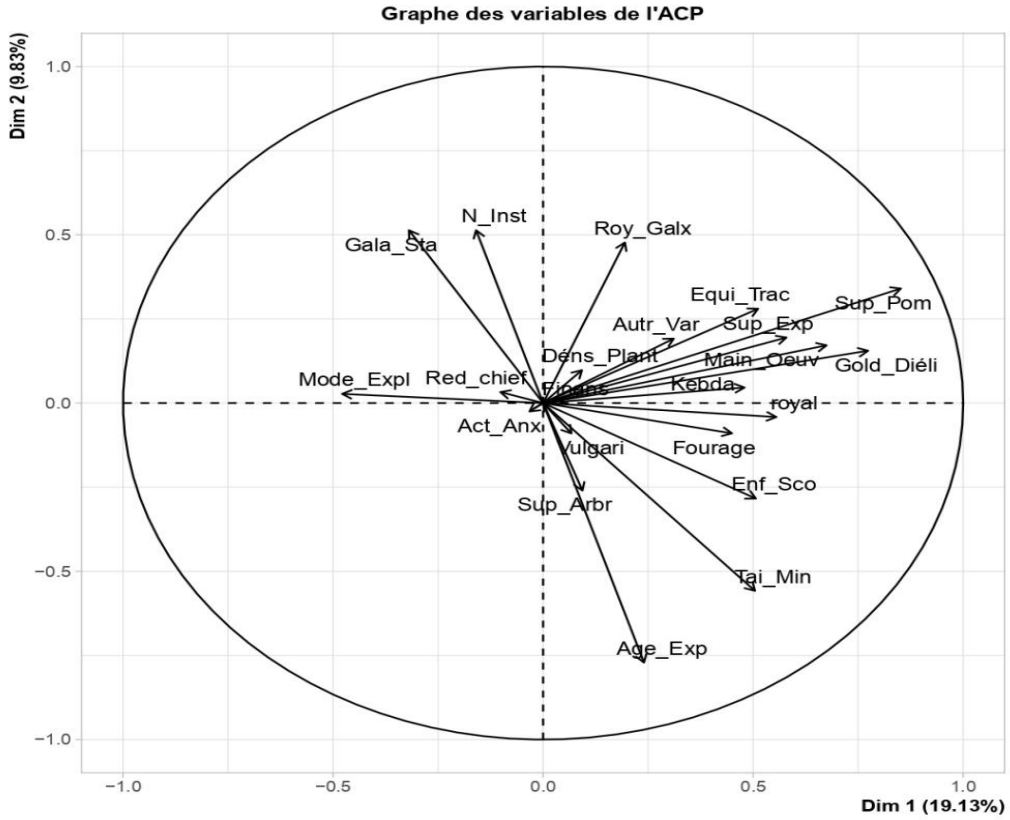


Fig N°4: variables correlation: there are in the circle, vectors that correspond to variables, which present a correlation more at least positive in the same side both left and right but also more at least

negative between the two parts, the correlation on the same side is positive as long as the vectors are of an angle more convergent and negative as long as the vectors are of an angle diverging

Meanings of abbreviations in APC variables graph:

(Gala Star=Gala_star variety), (Roy_Galx=Royal Galaxy variety), (Royal=Royal variety), (Red chief =Red chief variety), (Kebda=Top red variety), (Gold_Deli= Golden delicious variety), (Forage= Water well), (Mode_dexp = Farm purpose), (Dens_plan= Planting density), (Equi_trac = Agricultural machinery), (Main_doeuv =workers), (Sup_pom =Area apple orchard), (Sup_Exp =Farm area), (Activ_anx = Activity annex), (Niv_instr= Educational level), (Enf_sco =Number of children in school), (Tai_Min = Size of household), (Age_ Exp = Farmer age).

The APC variables graph show that:

With regard to the horizontal axis; The majority of variables have a positive correlation

there is a large positive correlation between the variables; area apple orchard (sup_pom), Golden delicious variety (Gold_délic) and workers (Main_oeuv)

There is a medium positive correlation between farm area (Sup_exp), Kebda (top red variety), number of children in school (Enf_sco) and water well (Forage).

With regard to the horizontal axis; There is a positive correlation between three variables; educational level, gala star variety and Royal galaxy variety

There is a negative correlation between the educational level and farmer age

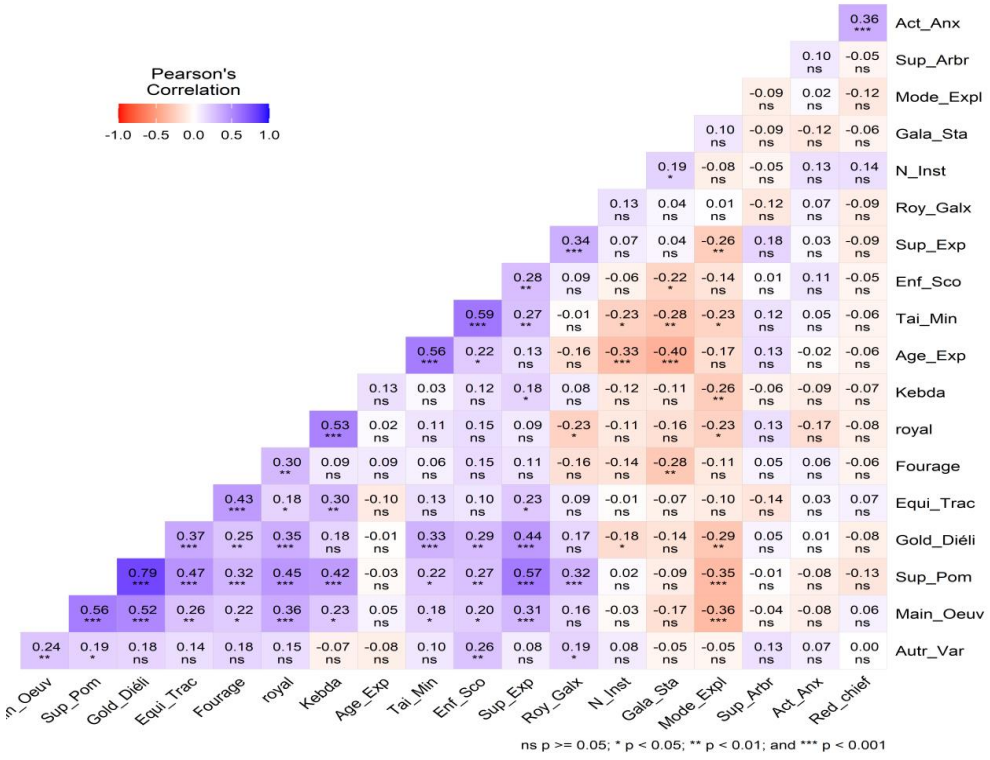


Fig N°5: Triangle of the Pearson correlation matrix; Pearson index values that correspond to study variables, blue means positive correlation, red means negative correlation, whenever the colour is low whenever the correlation is low and whenever the colour is strong whenever the correlation is high.
According to the results of the statistical analysis, there is four (04) farm classes,

Class 1 is represented by individuals (farmers) such as KH6 and KH21. This group is characterized by strong values for variables such as the Gala_Star variety and farmer educational level , and low values for variables including farmer Age, size of the household, number of children in school, workers, water well, farm area, Golden_Delicious variety, activity annex, and apple orchard area. This class primarily consists of young farmers with small household sizes, indicating that these are relatively new farms with a market-oriented focus but currently low yields. These farms are managed by young, educated farmers who constitute the majority of the workforce, often supported by their families. The majority of farms are typically small, with fluctuating land areas, and focus on modern, market-demanded varieties such as Gala Star. The Golden Delicious variety, valued for its storage resistance, is also maintained as a secondary crop.

Class 2 includes individuals (farmers) such as Y2 and Y12. This group is defined by strong values for farmer Age, size of the household, and activity annex, and low values for apple orchard area, Royal_Galxy variety, Gala_Star variety, mechanical equipment, farm area, Golden_Delicious variety, educational level, Top red variety and wokers. These farms are commercially oriented but managed by older farmers with larger households. The farm sizes are small, and the cultivation of varieties such as Gala Star and Golden Delicious is less prominent compared to Class 1. The workforce is predominantly family-based, reflecting a traditional farming structure.

Class 3 is represented by individuals such as B34. This group is characterized by strong values for planting density, and Royal_Galxy variety, indicating a higher planting density compared to other classes. The primary varieties cultivated are red apples, including Royal Galaxy variety, Geromine variety, and Chniko Red Gala variety.

This production system reflects an intensification strategy aimed at addressing the growing demand for food. However, farmers face significant challenges, including resource constraints, necessitating the adoption of practices such as increased input use, frequent irrigation, and enhanced pest and disease management. This system is critical for developing countries to achieve food self-sufficiency and boost export potential.

Class 4 includes individuals such as B4, B7, B10, B29, B39, B40, KH2, KH29, and KH38. This group is characterized by strong values for apple orchard area, farm area, Golden_Delicious variety, workers, mechanical equipment, top red variety, Royal_Galxy variety, water wells, and number of children in

school , These farms are typically large, market-oriented apple orchards managed by farmers with large families and a significant number of educated children. The workforce is substantial, and the farms are well-equipped with agricultural machinery and irrigation infrastructure. The primary varieties cultivated include Golden Delicious, Royal Galaxy, and Top Red (Kebda) varieties, reflecting a focus on high-quality, market-preferred apples.

The four (04) agricultural production systems in Khenchela is characterized by small-scale commercial farms, averaging 2 hectares in size. These farms are predominantly managed by farmers with an average age of about 48 with intermediate education levels, farmers who possess a solid understanding of modern farming techniques. Orchards are managed intensively, with the use of chemical fertilizers, growth regulators and fight against diseases to ensure high-quality commercial production. although mechanization is adopted in all necessary operations, 20% of farmers individually or collectively own tractors, small farms make the acquisition of agricultural equipment a low priority, Instead, they often rent machines for tasks such as ploughing and pesticide application

According to survey data, variety selection is primarily based on market demand, disease resistance, and storage suitability. This market-driven approach has led to the dominance of varieties such as Gala Star and Golden Delicious, which are favored for their commercial value and resilience.

3.2 Apple Production and Distribution varieties:

The Directorate of Agricultural Services (D.S.A) reports that during the 2018/2019 agricultural season, Khenchela was leader in the sector of apple production at national level with a production of 143500 tons, in 2023 the production rose to 1,815.46 tons (table 1).

Table 1: Evolution of apple production during the last years source (DSA the Agricultural Services Directorate 2023)

	2013/2014	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	2019/2020	2020/2021	2021/2022	2022/2023
Total area (Ha)	6194	6378	6660	6700	5264	6000	6007	5960	6050	6121
Related area (Ha)	4263	4947	5313	5400	4136	4200	4829	4752	5081	5264
Production (Qx)	348200	431082	1039876	1104247	1300000	1435000	1498191	1693185	1755814	1815460
Yeld (Qx/Ha)	56	68	156	166	314	360	310	356	346	345

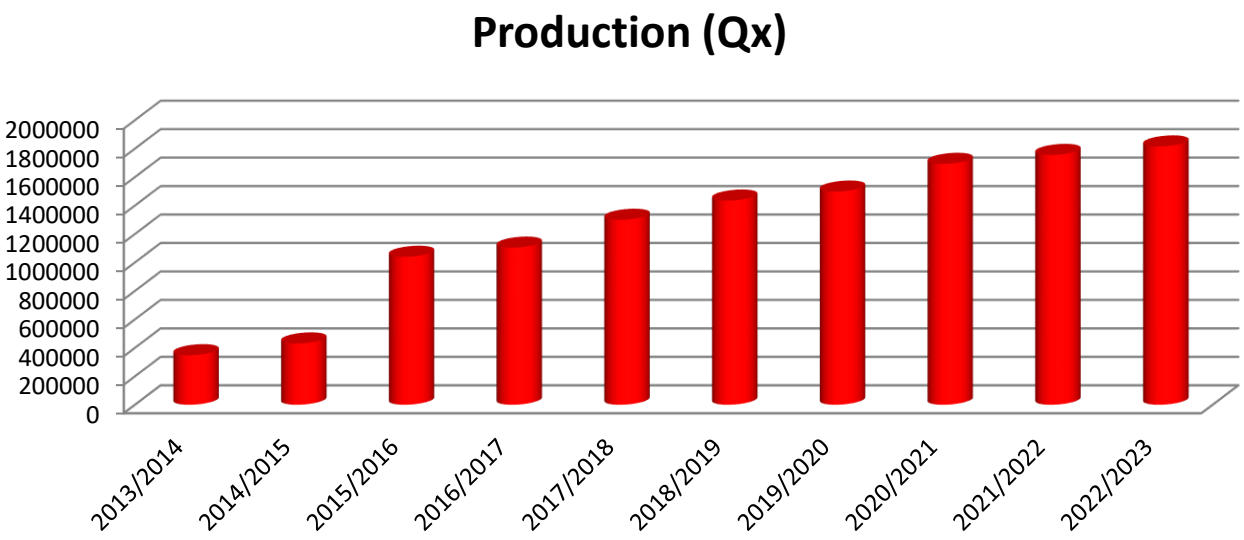


Fig. 4: Apple production between 2014 and 2023 (source: DSA: Agricultural Services Directorate 2023)

Depending on agricultural services directorate the Figure 4 illustrates a significant development in apple production in the late 1990s, driven by increased farmer interest in apple cultivation. This shift was largely influenced by the German-Algerian partnership, which transitioned farmers from traditional subsistence agriculture to market-oriented, single-variety apple production. The partnership introduced advanced cultivation techniques and encouraged farmers to adopt apple farming as an investment opportunity.

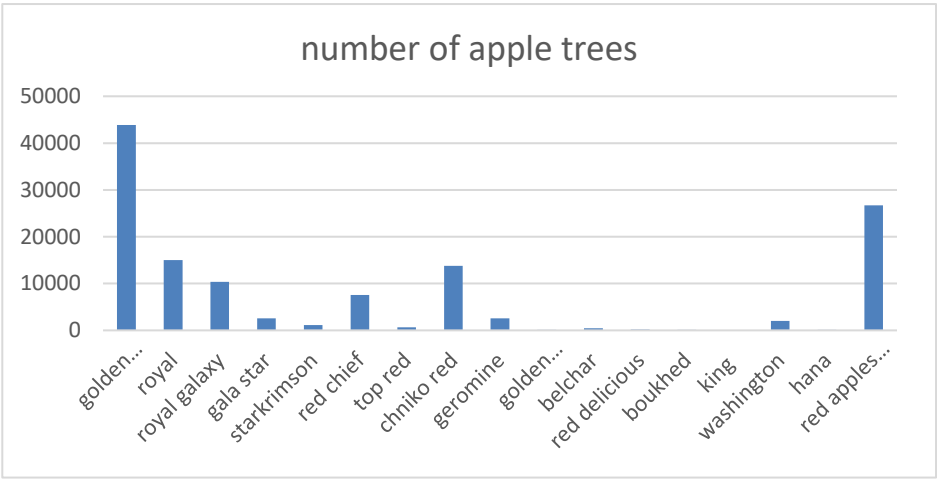


Fig. 5: **distribution of varieties in the orchards of the studied area**

According to our survey the graph (fig. 5) shows the varieties grown in the sample studied in the wilaya of Khenchela, such as golden delicious and red apples, which are the most popular in the

region. This is due to the large demand for them in addition to their adaptation to the mountainous character of the region and their monetary value in the market.

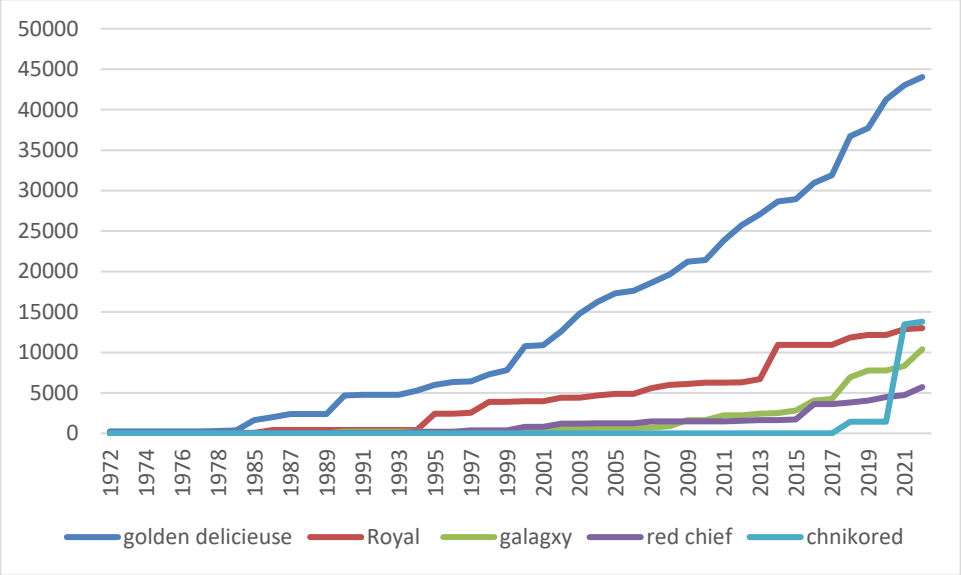


Fig. 6: The development of a number of apple tree varieties between 1972-2022 in the farms of 3 studied areas in Khenchela

The graph 6 show that the early 1980s is the importance that farms are beginning to attach to growing apples, and varieties that were initially grown in a large proportion and remained square in the foreground are Golden Delicious, followed by the royal variety.

There are the varieties Royal galaxy and red chief which were selected also from 1999

Over time, farmers gained expertise through interactions with producers from other countries and began experimenting with new, high-quality, early-yielding varieties.

In 2018, varieties such as the Gala Schnico Red had gained importance due to their market demand, adaptability and precocity; in 2021 this variety competed with the Royal and Royal Gala.

3.3 Management Practices:

In Bouhmama, farmers have progressively acquired knowledge of apple cultivation techniques through technical support from agricultural delegations and fertilizer suppliers. The latter have played a crucial role in guiding farmers during fertilization, pruning of fruit trees and pest control phases. To further enhance their skills, farmers established a cooperative "Bouhmama apple producers ", which have been instrumental in raising awareness, introducing high-quality varieties, and promoting best practices in chemical treatments and fertilization. The cooperative emphasizes the importance of adhering to recommended dosages and application frequencies to minimize environmental and health risks.

3.3.1 Control pest

Effective agrotechnical measures are critical for preventing pest outbreaks and reducing crop damage. For instance, timely harvesting and monitoring can mitigate the spread of pests such as aphids, which form colonies on shoots and leaves, causing significant damage to foliage and reducing yields (Uldasheva & Khamidov, 2022).

In Khenchela, apple orchards typically undergo 8 to 10 pesticide treatments per season. This contrasts sharply with practices in France, where apple orchards receive an average of 35 pesticide treatments annually, ranging from 27 in the North/Northwest to over 40 in the Central/West regions, depending on pest pressure (Agreste, 2018). Globally, apple fields receive an average of 29.5 ± 8.6 pesticide applications per season, with a total of 228 pesticide products containing 80 active ingredients (Johann et al., 2023). These findings highlight the need for improved pest management strategies in Khenchela to reduce reliance on chemical inputs.

3.3.2 Fertilization

In addition to chemical fertilization, the use of organic manure remains a common practice, helping to mitigate the negative impacts of excessive mineral fertilizer use. However, apple orchard management in Khenchela remains predominantly conventional, with limited efforts by authorities or agricultural associations to promote integrated or organic farming systems.

Organic farming has been shown to improve soil quality and provide effective pest control with reduced chemical inputs compared to conventional methods (Robert & Orpet, 2020). Despite its potential benefits, the transition to organic or integrated management in Khenchela has been hindered by a lack of institutional support and farmer awareness.

3.3.3 Irrigation Practices and Challenges

Irrigation in the three studied regions relies heavily on groundwater extraction, with over 60% of water sourced from boreholes, half of which are collectively owned. The drip irrigation system is widely adopted, installed on 95% of farms, reflecting a shift toward more efficient water use. However, farmers often resort to flood irrigation during periods of water scarcity or in the absence of adequate storage reservoirs, applying excessive doses exceeding 200 liters per tree. This practice, particularly prevalent in cases of collective borehole use, exacerbates groundwater depletion (ebbing), especially during prolonged drought periods.

Surface irrigation remains the most common technique globally, particularly among small-scale farmers, due to its low cost, simplicity, and minimal requirement for advanced hydraulic equipment or

technical expertise (FAO, 2002). Despite its widespread use, surface irrigation is highly inefficient, leading to significant water wastage and contributing to soil waterlogging and salinization. These issues are expected to persist, with surface irrigation likely remaining the dominant method until at least 2030.

Farmers in the region face numerous technical and economic constraints that hinder irrigation efficiency and farm profitability. High input costs, fluctuating market prices, and disorganized markets are among the primary challenges (Khiari & Sraoui, 2020). These factors directly impact farm operations, reducing their economic viability and sustainability. Addressing these challenges requires a multifaceted approach, including improved water management practices, investment in modern irrigation technologies, and the establishment of stable and organized market systems.

To enhance the sustainability of apple production in Khenchela, it is imperative to address the inefficiencies in current irrigation practices. Promoting the adoption of water-saving technologies, such as drip irrigation, and implementing policies to regulate groundwater use are critical steps. Additionally, providing farmers with access to affordable inputs, technical training, and market support can help mitigate economic constraints and improve the overall resilience of the agricultural sector.

3.4 Socio-economic environment

According to our study mentioned in (table 02), the family workforce occupies 48% of apple farming employment as the largest segment while 30% of employment is treated between family and seasonal workers.

Family farming constitutes a cornerstone of the agricultural sector, accounting for 80% of total employment in the three studied zones of Khenchela. This model of agricultural production has garnered significant attention within the social sciences due to its diverse manifestations and profound historical roots. As an analytical category, family farming gained prominence in the 1980s, coinciding with the transition from peasant studies to the examination of modernized agricultural units, where family farmers emerged as critical agents in sustaining rural economies (Rodríguez Zúniga & Soria Gutiérrez, 1985; García de Léon, 1996).

Globally, family farming represents the predominant agrarian model. In Europe, for instance, it comprises 97% of all farms and occupies 69% of agricultural land (FAO, 2019). Similarly, in Spain, 93% of the 914,871 farms are classified as family farms, contributing 63% of total agricultural employment (FAO, 2020). Family farming is defined by the intrinsic linkage between the production unit and the family, whether through ownership or leasehold arrangements. It primarily relies on

family labor, with limited or no permanent hired workers, and often involves the partial or predominant consumption of produce by the family itself (Bélières et al., 2014).

According to data we received from the Khenchela Agricultural Services Directorate, the apple sector employs 3,500 permanent workers and 12,000 seasonal workers,

Family farming is an essential mechanism for maintaining livelihoods, preserving traditional agricultural knowledge and fostering community cohesion. The use of family work facilitates the transfer of knowledge between generations, ensuring continuity in agricultural practices. on the other hand, the presence of four (04) cooperatives and six (06) agricultural associations contributes to the improvement of the Khenchela pome sector in technical and socio-economic terms and takes into account the concerns of farmers.

a wholesale market located in Bouhmama eliminates the marketing constraint, while a single storage unit with a capacity of 40,000 m3 in the wilaya of khenchela remains insufficient.

However, the predominance of small family farms also poses significant challenges, including limited access to modern technologies, financial resources and market linkages. These constraints underscore the need for targeted interventions to improve productivity, sustainability and resilience of family farming systems in the region.

Table 2: Type of labour force in the three study areas

Labour force (3 zones)			
Individual labour	Family labour	Seasonal labour	familial and Seasonal labour
6%	48%	16%	30%

4. Conclusion

The Wilaya of Khenchela plays a pivotal role in Algeria's apple production, contributing 25% of the national output, with an annual production of 1,815,460 quintals valued at 25 billion DZD (approximately USD 178,628,080). This study identifies four distinct apple production systems, The first category is characterized by the fact that farmers are young and the size of the small household this indicates that this group consists mostly of young farms with a commercial purpose, many of which have not entered the production phase, so the returns are low pending entry into the production phase. Led by young farmers who are themselves the workforce and their families, they are also often educated and engage in other activities in parallel, a production system that produces mostly small areas of farms with fluctuations in area between minimum and maximum, new and more sophisticated

varieties such as the much needed Gala star in the market, the golden delicious item that ranks second to the Gala star but still retains it as a cultivated item required in the market to resist storage. The second group is characterized by: Farms still for commercial purposes, owners are elderly they are also often uneducated with large households, Small size farms, unlike class one (1), , Galaxy varietie, Gala star, Golden, Red chief, is cultivated poorly in this category due to limited space, and the workforce in the majority is family, the third groupe present a higher planting density than other categories, some with a trellis system, mostly with hail net, the most cultivated variety is the red apple varieties such as the Royal Galaxy, Jeromin and the Cheniko Red Gala.
The farmers compensate for competition between trees and space, soil and water by inputs, increase the dose, increase the frequency of irrigation, fight against diseases and crop enemies; often early varietals. The 4th class is characterized by a large number of children educated (large family), large farms with market purpose and especially apple orchards so the number of workers employed is important and which presents a large number of drillings, The farm is equipped with agricultural machinery, ail net, the most cultivated varieties are golden delicious, royal galaxy and tope red (kebda).

The three areas are generally characterized by small family-run and self-financing farms averaging 2 hectares, intensive input use, and reliance on drip irrigation and floods, with yield of an average of 34.5 tonnes per hectares,. While the sector has achieved significant economic and social benefits, including 3,500 permanent seasonal and 12,000 seasonal rural employment, this agricultural activity has led to economic movements, notably with the availability of a wholesale market in the Bouhamma region, which has provided more marketing opportunities in addition to sales on the ground, and all these conditions have enabled the employment and participation of young people in the development process, but this socio-economic dynamic is opposed to a seriously challenge linked to the sustainability of resources such as the unsustainable use of water, climate vulnerability and limited sustainable practices. The study's limitations include potential biases from farmers' surveys and a narrow geographical concentration, which restricts the viability of outcomes. Future research should explore long-term environmental impacts, socio-economic barriers to sustainable practices and innovative water management strategies. By addressing these challenges through integrated policies, farmers' education, and scientific innovation, Khenchela can enhance the resilience and sustainability of apple production systems, ensuring their relevance to climate change and resource constraints.

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References

[1] Abdessemed, S., Fellak, A., Abdessemed, A., & Khan, A. *Status, challenges and opportunities for apple production in the Eastern Algeria*. *Horticultural Science* (Prague),49 (3), (2022). pp 147–153. https://doi.org/10.17221/123/2021-HORTSCI

[2] Agreste. *Apports de produits phytopharmaceutiques en arboriculture : Nombre de traitements et indicateur de fréquence* (No. 43). . (2018) Ministère de l'Agriculture et de la Souveraineté Alimentaire.

[3] Alaphilippe, A., Simon, S., Brun, L., Hayer, F., & Gaillard, G. *Life cycle analysis reveals higher agroecological benefits of organic and low-input apple production*. *Agronomy for Sustainable Development*, (2013). 33(3), pp 581–592. https://doi.org/10.1007/s13593-012-0120-y

[4] BNEDER. *Étude de faisabilité technico-économique de mise en valeur des terres par la concession périmètre de Bouilfane (15 ha)*, commune de Bouhmama. Ministère de l'Agriculture et du Développement Rural, (2017). Algérie.

[5] BNEDER. *Étude de faisabilité technico-économique de mise en valeur des terres par la concession périmètre de Glouaa Trab (25 ha)*, commune de Khirane. Ministère de l'Agriculture et du Développement Rural, (2019). Algérie.

[6] BENIDIR MEKKI., *projet Agro-sylvo-pasroral des zones montagneuses de la wilaya de Khenchela*, ministere de l'agriculture , 1994Agence Nationale des forets

[7] Bélières, J.-F., Bonnal, P., Bosc, P.-M., Losch, B., Marzin, J., Sourisseau, J. M., Baron, V., Loyat, J., Etienne, G., Lutringer, C., Faysse, N., & Léonard, E. *Les agricultures familiales du monde: Définitions, contributions et politiques publiques*. (2014). CIRAD/AFD.

[8] Berkani, C. *Traçage chimique et isotopique des eaux de sources pour la connaissance des aquifères du massif de l'Aurès, Khenchela-Algérie* [Doctoral thesis, (2016). Université de Khenchela].

[9] Cai, J., Xiong, J., Hong, Y., & Hu, R. (2021). *Pesticide overuse in apple production and its socioeconomic determinants: Evidence from Shaanxi and Shandong provinces*, China. Journal of Cleaner Production, 315, 128179. https://doi.org/10.1016/j.jclepro.2021.128179

[10] Chaumont, M., & Paquin, C. *Notice de la carte pluviométrique de l'Algérie* septentrionale au 1/500 000. Bulletin de la Société d'Histoire Naturelle de l'Afrique du Nord. (1971).

[11] DSA.. Statistics service. Agricultural Services Department, Ministère de l'Agriculture et du Développement Rural, (2023)Algérie.

[12] FAO*Sustainable development and natural resources management* (No. Paper C 89/2 – Sup. 2). (1989). Twenty-Fifth Conference, Rome.

[13] FAO. *Agriculture mondiale*: Horizon 2015/2030 (Rapport abrégé). . (2002)ISBN 92-5-204761-1.

[14] FAO. Eau et agriculture: *Produire plus avec moins d'eau*. Rome. (2002).

[15] García de Léon, M. A. *El campo y la ciudad: Sociedad rural y cambio social. Instituto de Estudios Agrarios, Pesqueros y Alimentarios*. (1996).

[16] Khiari, & Sraoui. *Contribution à l'étude de fonctionnement de système de production pommier dans la région de Kheirane (Khenchela)* [Master's thesis, (2020). Université de Khenchela].

[17] Lorenzo, B., Luca, N., Davide, N., Andrea, B., Simone, B., & Filippo, B. *Sustainability analysis of apple orchards: Integrating environmental and economic perspectives*. Journal of Cleaner Production, (2024). 315, 128179.

[18] MADR.. Le renouveau agricole et rural en marche: Revues et perspectives. Ministère de l'Agriculture et du Développement Rural, (2012), Algérie.

[19] Manning, P., van der Plas, F., Soliveres, S., Allan, E., Maestre, F. T., Mace, G., Whittingham, M. J., & Fischer, M.. *Redefining ecosystem multifunctionality*. *Nature Ecology & Evolution*, 2(3), (2018) 427–436. https://doi.org/10.1038/s41559-017-0461-7

[20] Ministerio de Agricultura, Pesca y Alimentación. (n.d.). Madrid.

[21] Pretty, J. *Agricultural sustainability: Concepts, principles and evidence*. Philosophical Transactions of the Royal Society B: Biological Sciences, (2008). 363(1491), 447–465. https://doi.org/10.1098/rstb.2007.2163

[22] Robert, J. O., Vincent, P. J., Elizabeth, H. B., John, P. R., Jessica, R. G., & David, W. C. (2020). *Perceptions and outcomes of conventional vs. organic apple orchard management*. Journal of Cleaner Production, 315, 128179.

[23] Rodríguez Zúniga, M., & Soria Gutiérrez, R. (1985). Lecturas sobre agricultura familiar.

[24] Salhi, M., & Ounassi, M. (2000). *La géologie générale de la wilaya de Khenchela (ville de Kais).* Journal of Cognitive Issues, 2602(7542).

[25] Uldasheva, S. K., & Khamidov, A. K. (2022). *Agrotechnological measures against apple pests in new intensive orchards*. Proceedings of International Conference on Scientific Research in Natural and Social Sciences.

[26] Zaller, J. G., Oswald, A., Wildenberg, M., Burtscher-Schaden, H., Nadeem, I., Formayer, H., & Paredes, D. (2023). *Potential to reduce pesticides in intensive apple production through management practices could be challenged by climatic extremes*. Journal of Cleaner Production, 315, 128179.

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