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The role of technological innovation in improving the quality and productivity of apiculture

Dr. Ziri Redhouene [1], Dr. Raoui Benamar [2], Dr. Mosbah Smail [3]

[1] Laboratory of Administrative Development to Promote the Economic Companies in the Wilaya of Ghardaia, University of Ghardaia, Algeria.Email: ziri.redhouene@univ-ghardaia.dz
[2] Laboratory of Modern Economy and Sustainable Development, University of Tissimsilt, Algeria
[3]Laboratory of Administrative Development to Develop the Wilaya of Ghardaia, University of Ghardaia, Algeria. Email: mosbah.smail@univ-ghardaia.dz
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Abstract:

This study analyses the role of technological innovation in improving the quality and productivity of apiculture. In so doing, we review Algerian and Arab literature to compare and find out more about the technological models used currently and assess their role in productivity and quality. The study uses the descriptive analytical method and analyses previous academic and experimental documents. Findings show 05 main models for technological innovation, namely the solar-heated hives, the mobile hives, the integrated beekeeping system, the green houses, and the digitalization. We presented these models in a statistical comparative frame to deduce the features of each and identify the most balanced and successful innovation that improves productivity and quality.

Keywords: technological innovation; apiculture; honey quality; modern techniques.

Introduction:

Recently, the agricultural sector has witnessed rapid structural changes due to environmental challenges, international market pressures, and need for a better production and quality. In this regard, the technological innovation is a strategic tool that can improve the quality of agricultural production thanks to modern techniques that improve the value series and foster competitiveness, mainly in vital sectors, such as apiculture that is a source for honey supply and a key factor for pollination and maintaining the biological diversity. Field studies revealed that integrating modern techniques in the sector, either for breeding or marketing, has a direct effect on the productivity and on the quality of the final product; therefore, the technological innovation is a key determinant of the sustainability and development of apiculture. Despite the increasing interest in innovation in the agricultural sectors, it is still limited in apiculture; what raises questions on the role of technological innovations in improving quality and increasing productivity. Based on what was said, we raise the following problematic, "**to what extent does technological innovation improve quality and productivity in apiculture?"**. From this question, sub-questions arise as follows:

- What is the status-quo of apiculture? What are its main phases and types?
- What are the main technological models adopted currently?
- What is its real effect on the economic and technical performance of apiculture?

Axis one: The Theoretical and Conceptual Frames of Technological Innovation and Quality of Agricultural Product:

1. Definition of Technological Innovation and Comparison to Similar Concepts:

It is the process of developing a product, services, or productive process using technical and scientific knowledge to improve quality, performance, or cost[1]. This definition shows the practical dimension of the concept, as the technical knowledge is not enough without a real productive practise that affects the company's general performance. Thus, the technological innovation is a strategic tool to achieve the operational efficiency and respond to market fluctuations. Besides, innovation is the process of improving existing products, goods, or productive process or designing new ones[2]. This definition shows that innovation covers all the activities of the company, including distribution, marketing, and services, not only the technical activities; therefore, it is an integrated process in the macro structure of the company that fosters the value added.

Moreover, the innovation is the output of an interaction between creativity and the ability of practical application[3], as the application distinguishes innovation from invention. In this context, each invention is not an innovation unless it is practical and economically employed. This premise reveals the dual structure of innovation, as it does not end at producing knowledge; rather, it requires an environmental and institutional context that allows for promoting knowledge and achieving an economic effect. This shows the need for resources, administrative support, and an organizational culture that embraces change. On the other hand, development refers to the process of a gradual improvement of an existing product or service. Therefore, development is a preliminary or median step towards innovation[4]. In addition, innovation is a qualitative step that requires a higher level of renewal and risk-taking, and marks a strategic change in the company.

2. The Types of Technological Innovation:

The technological innovation has different types based on the nature and aims of the company. Therefore, it is divided into product innovation, process innovation, incremental/continuous innovation, and radical innovation.

1. Product Innovation:

It is introducing new goods or services or improving the characteristics, performance, shape, or design of an existing product to satisfy new needs or improve response to current needs[5]. It reflects the market nature of innovation, as it is directly linked to the customers' changing needs and expectations, and is an indicator of the company's ability to turn the technical knowledge into a tangible value added, mainly in the food and agricultural industries that require a high qualitative adjustment of products.

2. Process Innovation:

It is about improving the methods adopted in producing goods or delivering services to increase efficiency, reduce cost, save time, and maintain quality[6]. Such type is the main engine to improve the internal performance of companies, as it focuses on the operational structure and product quality. In

[1] Jassem Ali Mohamed al Tahan (2016), innovation: the content and variables, university book house, UAE, Vol. 01, p. 43.

[2] Marwa Ramdani & Karima Bouguerra (2020), the challenges of start-ups in Algeria: models of successful Arab start-ups, annals of Bechar University in economics, Vol. 07, issue 03, p. 279.

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[4] Cynthia, W. W., Harry, T. C., & Ravi, K. j. (2010). managing research, development, and innovation - Managing the Unmanageable- (Third Edition ed.). Canada: Published by John Wiley & Sons.06.

[5] Ahu Tugba Karabulut, 2015, Effects of Innovation Types on Performance of Manufacturing Firms in Turkey, Procedia - Social and Behavioral Sciences journal 195, p.1357.

[6] Mohamed Quraichi & Sami Mebarki, the role of technological innovation in improving the economic performance of companies, journal of human sciences, University of Mohamed Khider in Biskra, Algeria, issue 25, June 2016.

the agricultural sector, it develops irrigation systems, automation, and cooling chains.

3. Incremental/Continuous Innovation:

It is the set of accumulating gradual improvements on the product or the process without radical change in the function or the structure[7]. It is adopted in limited resources companies or in the sectors that need continuous improvements to ensure competitiveness. It suits the small and middle-sized agricultural companies that rely on quality and continuity instead of sudden changes.

4. The Radical Innovation:

It is introducing new productive concepts or techniques that change the nature of the product or its manufacturing method after the establishment of new markets or reshaping the existing ones[8]. It is a revolutionary type marked with high risks and funding. However, it allows the company to reposition itself in the market. In the agricultural field, it manifests in vertical agriculture techniques and the automatic control of the smart fields' climate.

3. Characteristics of Technological Innovation in the Agricultural Sector:

In agriculture, the technological innovation is different than the other sectors due to its relation with the natural environment, diversity of production types, and limits of companies' investment power. Its main characteristics are:

1. Environmental Dependency:

The agricultural innovation is characterized with its direct interaction with the natural items (climate, soil, water). It requires innovations to be adjustable to the local biological and environmental variables[9], what marks the main challenges for innovation in agriculture, as it is not possible to transfer any ready technique from the industrial sector and apply it, as it is, on the agricultural environment. In this regard, success depends on the suitability of innovation to the local climate and the available resources. Therefore, the agricultural innovation requires an exact adjustment more than a mere adoption of technology.

2. The Techno-economic Compatibility:

The agricultural innovation must show economic and technical efficiency so that producers can adopt[10] it, as the technique must be at suitable economic costs and yield clear economic returns, mainly for small farmers and start-ups. Thus, technology pricing and methods of its purchase are decisive for its adoption and spread.

3. Incremental Adoption and Knowledge Accumulation:

Adopting innovation in agriculture is often gradual to allow for experience accumulation and risk reduction. Thus, the comprehensive experimentation in innovation is a risk that may cause big losses. Therefore, producers, usually, prefer limited experimentation and, then, gradual expansion. This explains the gradual adoption of innovation and shows the importance of training for innovations generalization[11].

4. The Impact on Food Quality and Safety:

The agricultural innovation has direct effects on the quality, value, and health criteria of the product. In this context, innovations increase production and improve characteristics to satisfy the consumers' demands and the health systems. Therefore, innovation is a strategic tool to ensure quality

[7] Mohamed Quraichi & Sami Mebarki, op. cit., p. 411.
[8] Ibid.
[9] Salwa Dhib & Abd al Hak al Aifa, the technological innovation of start-ups in agricultural engineering: the vertical agriculture as a model, University of Ferhat Abbas in Setif 1, Algeria, journal of economic studies, Vol. 12, issue 01, 2024, p. 50.
[10] Ibid., p. 53
[11] Salwa Dhib & Abd al Hak al Aifa, op. cit., p. 102.

and get conformity certificates to penetrate local and international markets confidently.

5. Integration with Digital Transformation:

The modern agricultural innovation highly depends on digital instruments, such as sensors, automatic control systems, and data analysis. Digitalization complements the agricultural innovation because it reduces costs, increases exactness, and enhances decision making. In this regard, exact agriculture and IoT Agriculture are necessary in modern farms to control resources and improve tracking and production in real time[12]. Understanding technological innovation in agriculture requires good awareness about the environmental and social contexts, as success depends on the implementability and acceptance of technology, not only on its availability. Therefore, the agricultural innovation is a complex process that requires cooperation of producers, researchers, and rulers.

4. The Concept of Agricultural Product Quality: Economic and Technical Perspectives:

Quality is the degree where the product characteristics satisfy the consumers' explicit and implicit needs and expectations[13]. This definition focuses on the objective and perceptional perspectives of quality; the first manifests in the measurable characteristics, such as shape and solidity, while the second is based on the consumers' perceptions. Such balance is vital in agriculture because of the diversity of consumers and of their quality criteria (taste, colour, and nutritional value). In this context, consumers usually match quality with conformity, not only the specifications. For instance, vegetables, honey, or milk must meet the expected nutritional or therapeutic purpose, not only the technical specifications.

Economically speaking, quality is a strategic tool to foster competitiveness, satisfy customers, and foster loyalty. Besides, high-quality products allow the company to enter international markets and get ISO and GlobalGAP certificates[14]. Thus, quality is an economic choice that allows for a wider market share, better gains, and less losses, as long as quality criteria are respected in production, transportation, packaging, and conservation. In sum, the quality of the agricultural product is a complex structure that combines technical points (conformity, hygiene, and nutritional specifications) and the economic expectations of consumers and markets (taste, price, and loyalty). In the agricultural context, it depends on the environmental resources and conditions.

5. Quality Evaluation Criteria in Agricultural Products: Sensory – Nutritional – Marketing:

The quality of the agricultural product is measured with different criteria based on the type and purpose of the product.

First: Sensory Attributes:

They cover the characteristics that can be perceived with senses, like colour, odour, taste, shape, and texture, mainly in fresh products, such as vegetables, fruits, and honey. Besides, quality assessment covers durability, aesthetics, and reputation because they affect the purchase decision. The sensory attributes are decisive in the agricultural market because they highly affect the consumer's trust, as the product that looks fresh, clean, and natural has better sale chances even if it has less nutritional values.

Second: The Nutritional Attributes:

They cover the nutritional value of products, such as vitamins, proteins, minerals, and absence of pesticides. The technical

[12] Hammoud Khider Kadhem, the management of comprehensive quality, al Massira house for distribution and printing, Amman, Jordan, 2000, p. 102.

[13] Mohamed Korachi & Sami Mebarki, op. cit., p. 404

[14] Ghassan Gasem Daoui al Lami & Athir Abdullah Mohamed al Soudani, the effect of the characteristics of knowing the job on the dimensions of product quality, journal of administration and economics, Faculty of Administration and Economics, University of Baghdad, Iraq, issue 68, 2008, p. 62.

quality is measured with physiological, chemical, and biological criteria, which reflect the product's conformity with the health and nutritional requirements, help classify the products into products with high or with average quality, and determine the product's exportability.

Third: The Marketing Attributes:

They cover the product's ability to compete in the market through its brand, packaging, storage, expiry date, easiness of transportation, and seasonal demand. They are a marketing tool that affects the consumer's perception of the product and fosters the company's image and reputation thanks to tracking and after sale service. For example, smart packaging may protect and extend the life of the product, and the strong slogan and good marketing foster sales even under competition.

6. The Relationship between Technological Innovation and Agricultural Product Quality:

The product quality determines the ability of the agricultural company to compete nationally or internationally, and is key for the product's acceptance or refusal by the consumers. In this regard, the technological innovation enhances the quality of the agricultural product by developing new production methods, adopting modern procession techniques, and improving the production inputs[15]. The integration of automatic control system and precision agriculture increases production precisions, reduces the losses, and improves quality without direct increase in costs. This perception mirrors the direct relation between innovation and quality, as each successful technical improvement fosters the product's position within the market, fosters customer satisfaction, and enhances demand. In addition, the introduction of new products or productive processes, or the improvement of existing ones, positively affects quality[16]. Moreover, the technological innovation helps companies unify specifications and control quality to integrate into comprehensive quality systems.

Axis two: The Technological Innovation and the Development of Apiculture Outputs:

1. Apiculture Definition and Environmental and Economic Importance:

Apiculture is an agricultural activity that focuses on keeping honey bees in prepared hives to produce honey and its derivatives and provide vegetal pollination services that improve the agricultural crops and the biological diversity[17]. It ensures food security and fosters rural development because it is a low cost activity that can be part of family plantations. In addition, it is eco-friendly, preserves the environmental balance, and encourages the sustainable agricultural practices, mainly in mountains and semi-arid regions[18].

2. Apiculture Phases

1. Preparation and Planning:

This phase is about choosing the site, providing the suitable hives, looking for nectar-rich pastures, and preparing the primary tools[19]. This foundational phase requires deep

[15] Ghassan Gasem Daoui al Lami & Athir Abdullah Mohamed al Soudani, op. cit., p. 65.

[16] Mohamed Suleiman, marketing innovation and its effect on the improvement of the company's performance : case study of al Hodna Diary in Msila, unpublished Magister thesis in marketing, University of Msila, 2007, p. 26.

[17] Derrar Lamine & Adila Mermit, the effect of innovation on the outputs of agricultural projects- case study of apiculture in the Algerian East, journal of studies in economics and business management, Vol. 04, issue 02, December 2021, p. 136.

[18] Nour Djawad Mezra al Khafadji & Achwak Abderrazzak Nadji al Badri, the advisory agricultural innovation for beekeepers to develop and increase productivity in the Central Region of Iraq, journal of Iraq agronomy, Vol. 47, issue 05, 2021, p.p. 134-136.

[19] Youcef Tawfik Georges Wassif, analytical econometric study of honey production in Egypt, case study of Assiot Province, the Egyptian journal for agricultural economy, issue03, 2021, p. 1046.

knowledge of the vegetal environment and the climatic conditions to ensure food stability and product quality.

2. Colony Management and Care:

During this phase, bees are fed and checked to fight problems like Varroa Destructor and ensure the hive stability. It requires continuous training of beekeepers, as studies revealed that low training decreases production and increases losses. Therefore, agricultural guidance must be integrated into each phase[20].

3. Harvesting and Processing:

This phase is about extracting honey, separating wax, and collecting pollen and royal jelly[21]. It reflects the success of the previous phases and is highly affected by the hive type, used tools, and beekeeper's experience.

4. Marketing and Commercialization:

It includes packaging, storage, and looking for local or international commercialization channels. Marketing raises many issues, mainly with the lack of strong commercial brands and product valorisation mechanisms. In this regard, innovative packaging is decisive for access to high criteria markets.

3. Types of Bees and Hives:

First: Types of Bees:

- Apis Mellifera: It is the most used worldwide for its high productivity and adaptation to different environments[22].
- Local bees: This type supports high temperatures and resists some diseases, but is less productive.
- Caucasian bees: It is known for its calm and friendliness; it is best used in commercial apiculture.
- Arid regions bees: This type adapts with the arid climate and is raised in mobile hives to look for plants[23].

The type choice is a crucial technical decision that affects productivity and diseases resistance, as modern practices showed that hybridizing species enhances performance in harsh climatic conditions.

Second: Types of Hives:

- Traditional hives: They are made up of clay, are less productive, and usually need manual efforts.
- Langstroth hives: They are made up of wooden boxes with tyres, and are usually used for wide regular commercial production.
- Mobile solar hives: They are transportable and can be moved in flowering seasons; they are used in keeping nomadic bees[24].

The hive is the technical infrastructure for apiculture and highly affects the honey quality and administration and bee safety. The mobile hives are a practical solution against the seasonal changes. In this context, apiculture is an integrated system that incorporates scientific knowledge and agricultural experience, and is a cornerstone in rural economy and sustainable development. Moreover, the integration of technological innovation into all its phases (from keeping to commercialization) is necessary to improve productivity and achieve international quality criteria.

4. The Technological Models for Improving Apiculture Productivity and Quality:

The technological innovations contribute to the development of apiculture because they introduce new methods of keeping and production to get a better

[20] Ibid.
[21] Ibid., p. 1047.
[22] Winston, M. L. (1987). The Biology of the Honey Bee. Harvard University Press.
[23] Derrar Lamine & Adila Mermit, op. cit., p. 137.
[24] Farid Ahmed Khaled, the linear programming : an innovative tool to decrease the costs of transporting beehives, case study of Daif Allah & Co. for apiculture in Boufarik, journal of growth and outlook for studies, 2020, p. 83.

performance, improve exploitation, reduce costs, and ensure the highest quality of products. Our practical study on apiculture in the Algerian East reveals 05 main models of apiculture, namely:

1. Solar-Heated/ Thermosolar Hive:

It is an innovative model against Varroa Destructor, as it increases the hive temperature to 40- 47°C for 15 minutes thanks to a solar-powered furnace. The treatment is reaped after 10 days to ensure the full eradication of parasites that had been outside the hive during the first session without any chemical intervention[25]. Such technique is very efficient against fungal diseases, reduces the costs of chemical treatments, fosters the sustainability of healthy apiculture, and preserves the environment against pollution.

2. Mobile Apiculture System:

It is about transporting hives by trucks equipped with solar panels and electrical generators towards flowering regions. In addition, trucks are equipped with automatic heating systems that work automatically when temperature decreases[26]. This system extends the annual production phase, diversifies nectar sources, improves the vegetal composition of honey, reduces artificial nutrition costs, and fosters production and transportation flexibility.

3. Integrated Apiary System:

It requires agricultural units that include pastoral plants, fruitful trees, aromatic crops, and health control equipment to provide a balanced nutritional environment for bees and increase productivity[27]. It reduces dependence on external nectar, allows for fixing hives in stable productive sites, reduces mortality rates, increases complex production (honey, way, jelly), improves complementarity between the agricultural activities in one farm, and promotes for the concept of the circular agriculture.

4. Plastic Greenhouses for Beehive Protection:

It is used in regions with harsh climates, particularly in mountains and deserts. In this context, bees are put in greenhouses to manage temperature and precipitation and protect them from rain and wind in winter[28]. It reduces seasonal deaths, fosters stability, and allows for production in months where production had been impossible.

5. Analytical Comparative Study of the Technological Models:

The statistical data in table 01 are the outcome of qualitative analytical scaling based on the practical studies. We used relative scaling for analytical comparison to show the different effects of the technological models. These results cannot be subject to strict statistical examination; rather, they support the comparative comprehension of technical and functional performance of each innovation.

Technological model	Productivity increase %	Cost reduction %	Honey quality (out of 5)	Reliance on local sources (%)
Solar heated/ Thermosolar hives	20	30	4.5	85
Mobile apiculture system	25	20	4.7	70
Integrated apiary system	18	25	4.4	90
Plastic greenhouses	15	18	4.2	60

[25] The effect of innovation on the outputs of agricultural projects, apiculture in the Algerian East, journal of studies in economics and business management, issue 04, 2021, p. 138.

[26] Ibid., p. 83.

[27] Ibid., p. 95.

[28] Farid Ahmed Khaled, op. cit., p. 78.

Digitalization and smart management	22	28	4.8	75

Conclusion:

The statistical comparison of the technological models of apiculture shows different effects on production, quality, and costs. For instance, the mobile apiculture system ensures the best productivity, as it allows for extending the annual activity and for diversifying the sources of natural nectar. In addition, digitalization and smart management system shows excellent performance thanks to the temporal data and interventions in due time. Regarding costs, the solar-heated hives can reduce treatment costs thanks to natural heating techniques. In the same context, digitalization reduces reliance on the continuous manual work. Concerning the honey quality, digitalization proved the best choice because the precise control helps maintain optimal conditions inside the hive to produce purer honey with higher nutritional values. Furthermore, the integrated apiary system shows the best results in reliance on local resources, as apiculture is exercised within an integrated agricultural environment that provides natural food for bees and reduces the need for external products.

In the end, we conclude that:

- The mobile apiculture system is the best option for increasing productivity thanks to the diverse sources of nectar and the extension of the annual activity period.
- The solar-heated hives show high efficiency in reducing the operational costs because they decrease reliance on chemical treatments and foster the use of the solar energy.
- Digitalization and smart management ranked first regarding the quality of honey because they allow for managing the climatic conditions automatically with less manual interventions.
- The integrated apiary system highly relies on the local resources and fosters economic and environmental sustainability in production.
- Digitalization is the most balanced technological innovation because it combines high production, cost management, and quality assurance.

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